ADHD and Reasoning Performance:

Bridging the Gap between Science and the Classroom

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By

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ABSTRACT

Decision errors occur because faster, Type 1 processes supply an autonomous dominant response founded on beliefs that can be difficult to inhibit and override by slower Type 2 processes correlated with more rational thinking. ADHD is widely associated with primary deficits in inhibitory control (Barkley, 1997), a central executive mechanism that plays a principal role in analytic thinking. Differences in reasoning abilities between university students with ADHD (n = 64) and without (n = 64) were measured by asking both groups to solve 24 base-rate problems (12 conflict, 12 non-conflict) that included a response instruction manipulation of answering either with “beliefs” or “statistics.” Participants also completed the Cognitive Reflection Test (CRT), a three-item problem-solving task that cues an intuitive, yet erroneous, response that must be inhibited and overruled to provide a correct answer. Surprisingly, accuracy rates for ADHD participants on the CRT task matched that of controls. Similarly, ADHD participants performed equal to or better than controls on base-rate problems thought to require inhibitory control. The pattern of response times for both study tasks suggests that the acknowledged inhibitory deficits in ADHD may manifest themselves in response latencies. Thus, despite similar or better accuracy rates, ADHD reasoners required extended time to overcome inhibitory deficits. A further finding was that on base-rate problems solved with beliefs, on conflict and non-conflict problems, the ADHD group required significantly longer to encode the lengthy personality descriptions. Likely this is due to inefficient working memory systems, strongly associated with ADHD, that hamper the ability to temporarily store and manipulate information (Holmes et al., 2014). Altogether, these findings have implications for classroom instruction for students with ADHD and may assist with developing effective pedagogies to provide a positive and rewarding learning experience for students with diverse learning needs.

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"Friends are as companions on a journey, who…aid each other to persevere on the road to a happier life." (Pythagoras)

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LIST OF ABBREVIATIONS

ADD	Attention deficit disorder
ADHD	Attention deficit/hyperactivity disorder
ADHD-C	ADHD, combined subtype (ADHD-H and ADHD-I)
ADHD-H	ADHD, predominantly hyperactive/impulsive subtype
ADHD-I	ADHD, predominantly inattentive subtype
ANOVA	Analysis of variance
APA	American Psychiatric Association
CAS	Cognitive Assessment Tool
CRT	Cognitive Reflection Test
DSM-5	Diagnostic and Statistical Manual of Mental Disorders - Fifth Edition
MPH	Methylphenidate
DPT	Dual Process Theories (of reasoning)
DSS	Disability Services for Students
PASS Theory	Planning, Attention, Simultaneous and Successive Processing theory of brain function components
PREP	PASS Remedial Program
WAIS	Wechsler Adult Intelligence Scale
WISC	Wechsler Intelligence Scale for Children

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CHAPTER 1

INTRODUCTION

Rapid advances in modern technology and innovations in science have provided us with a comprehensive understanding of the brain's interactive functioning in learning, cognition, and neurological processing. Collaborative research in neuroscience, psychology, and pedagogy has advanced our understanding of how the brain learns best and identified obstacles to learning. *Mind, brain, and education science*[1] is the "new" *brain-based education* that is spurring a radical shift in how we think about education and how we teach our students (Tokuhama-Espinosa, 2011). Why is this necessary? Tokuhama-Espinosa explains that students' complex learning needs may not be addressed successfully through pedagogical approaches alone. The "new science" of teaching and learning has integrated knowledge from fields of neuroscience, psychology, and education, and applied this expertise to the school setting. Pedagogical advances, innovative teaching, and optimization of learning conditions are a natural corollary of multidisciplinary research that supports all types of learners (Tokuhama-Espinosa, 2011), including those with disorders that impair *executive functioning*, such as *attention deficit/hyperactivity disorder (ADHD).*

ADHD as a Neurodevelopmental Disorder

Since its initial depiction in medical literature as an "abnormal defect of moral control in children" (Still, 1902), what we now identify as ADHD was described for decades as simply a disruptive behavioural disorder commonly seen in boys (Brown, 2013). Major changes in the conceptualization of ADHD came in the 1980s when, despite still being classified as a behavioural disorder, the third edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-III; American Psychiatric Association [APA], 1980) attached the designation of "*attention deficit disorder*" (ADD) to highlight attentional impairments. Further modifications in the DSM-IV (APA, 2000) resulted in a name change to that of ADHD and established the three subtypes used by health care professionals today: combined type ADHD-C; predominantly inattentive type ADHD-I; and predominantly hyperactive-impulsive type ADHD-H. In 2013, the DSM-5 reclassified ADHD from a behavioural disorder to a neurodevelopment disorder (APA, 2013). While we have come far in understanding more about this disorder, there is still much to

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[1] Items in italics indicate the item is listed in the Definition of Terms (pp. 7-10)

be learned about the differentiated subtypes, their biological basis, and the negative consequences on meta-cognitive processes that regulate reasoning, and decision-making.

The classification of ADHD subtypes is still being actively debated. For example, researchers argue that subtypes ADHD-H (typically diagnosed between 3-4 years; Applegate et al., 1997) and ADHD-C (commonly diagnosed between ages 5 and 8) may simply be developmental stages of the same disorder (Barkley, 1997a, 1997b, 2006; Nigg & Barkley, 2014). ADHD-I symptoms of *selective attention* deficits and sluggish cognitive processing may actually be related to "impaired *working memory* and not of perceptual, filtering, and selection (input) problems" (Barkley, 2003a, p. 78, 2003b, p. 77, but see also Barkley, 1997a), although the exact neurobiological deficits remain unknown (Nigg & Barkley, 2014). It currently remains unclear whether this inattentive subtype has distinct deficits (Barkley, 1997b; Carlson & Mann, 2000). Some argue for ADHD-I to be classified as being a unique disorder from ADHD (Barkley, 2001, 2006; Carr, Henderson, & Nigg, 2010; Milich, Ballentine, & Lynam, 2001). Although ADHD has benefitted from a plethora of research, there remains much that we do not know about the various subtypes and their origins.

Most neuropsychologists agree that, on a biological basis, those with ADHD have difficulty managing impulses, controlling movement, sustaining attention, and engaging in self-disciplined behaviour. Yet controversy continues regarding the biological cause and neuropsychological impairments associated with ADHD. Research employing factor analysis (Burns, Boe, Walsh, Sommers-Flanagan, & Teegarden, 2001) has identified two qualitatively different core behavioural dimensions underlying the various symptoms thought to characterize ADHD– one driven by inattention (ADHD-I), the other driven by hyperactivity-impulsivity (ADHD-H). The focus of this paper is on the more dominant manifestation of the disorder, that of the combined type ADHD (ADHD-C), a combination of ADHD-I and ADHD-H. Those with ADHD-C are thought to have significant deficits in behavioural inhibition and inattention (the executive functions) that are critical for effective *self-regulation* and *behavioural inhibition* (Barkley, 1997b; for a review, see Nigg & Barkley, 2014).

Although the current DSM-5 continues to emphasize the behavioural symptoms of inattention in its diagnostic criteria, emerging literature provides strong evidence that impairment in self-regulation and executive functioning offer a better explanation of impairment in ADHD (Nigg & Barkley, 2014). Researchers and clinicians could benefit from examining ADHD from a cognitive and neuropsychological perspective. Converging lines of research, including measures of physiological functioning, laboratory tests, and neuroimaging studies increasingly support *disinhibition* as a core deficit of ADHD-C (for a review, see Harrier & DeOrnellas, 2005; see also Nigg & Barkley, 2014; Wellington, Semrud-Clikeman, Gregory, Murphy, & Lancaster, 2006). Barkley (1997a) posits that "ADHD-C represents a profound disturbance in self-regulation and organization behaviour across time" (p. vii), functions that are subserved by prefrontal, mid-brain, and cerebellar regions in the human brain (Fisher et al., 2002). The acknowledgment that dysfunctional neurological processes in the central executive system are the biological basis of ADHD brings us back to the earlier discussion on the collaborative approach to science in mind, brain, and education and the concept of "brain-based education."

ADHD and Implications for Reasoning Performance

The progressive edge of modern science demonstrates the necessity for a multidisciplinary approach to understand the complexity of human brain function, as opposed to a fragmented approach (Brown, 2006). Advances in neuroscience imaging have quite literally provided a clearer picture of the complex neurological underpinnings of ADHD. Traditional tests of executive functioning (see Table 1) corroborate the executive processing deficits recognized in ADHD. However, this constructs an overly reductionistic interpretation of complex cognitive operations (Brown, 2006) that does little to advance interventions, generate innovative teaching methods, and optimize learning environments. As Brown notes, executive function deficits do not segregate their effects to discrete and isolated mechanisms. Rather, the negative consequences of frontal lobe impairments resemble disruptions in a computer operating system that interfere with the reliability and smooth running of multiple software programs. A multidisciplinary approach with respect to ADHD could determine how neurological impairments of executive brain processes affect the complex interaction of multiple cognitive components in applied tasks of thinking, reasoning, and decision-making. Ultimately, the overarching goal is to merge this knowledge with novel approaches to generate innovative teaching practices that enhance or compensate the brain's learning capacity.

Extensive research has examined ADHD in terms of the brain's neurological reinforcement and extinction mechanisms that alter behaviour (e.g., Johansen, Aase, Meyer, & Sagvolden, 2002), probabilistic learning via monetary rewards and punishments, (e.g., Garon, Moore, & Waschbusch, 2006; Luman, Oosterlaan, Knol, & Sergeant, 2008; Masunami, Okazaki,

& Maekawa, 2009), *inhibitory control* of executive functions (e.g., Clark et al., 2007; Schachar, Mota, Logan, Tannock, & Klim, 2000), and working memory deficits (for a review, see Au et al., 2014; see also Holmes et al., 2010; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Questions remain as to how acknowledged central executive deficits in the ADHD brain, specifically inhibitory control, might impair the ability to perform decontextualized reasoning (reasoning logically from premises irrespective of personal beliefs or context; Moshman & Franks, 1986) when reasoning on logic or probability problems that might parallel those given in the classroom. A 2014 data base search of MEDLINE/PubMed, Education Resources Information Centre (ERIC), and PsycINFO using the keyword of ADHD paired with phrases of executive function, inhibitory control, executive inhibition, *response inhibition*, working memory, abstract reasoning, *logical reasoning*, or probability reasoning produced no results of applied studies of this nature. To this author's knowledge, no study has investigated how executive deficits of inhibitory control, as thought to occur with the psychopathology of ADHD, might impair the reasoning performance of individuals with ADHD on problem-solving tasks that require the inhibition of irrelevant information to produce a "correct" or *normative response* based on logical principles.

Study Purpose and Overview

The purpose of this thesis is to study how individuals diagnosed with ADHD perform in abstract reasoning, as compared with a control group of individuals without ADHD. The primary focus is on potential differences between the two groups' abilities to inhibit or suppress one source of information over another when instructed to solve *traditional base-rate* problems either by "statistics" or "beliefs." Consider, for example, the following base-rate problem from De Neys and Glumicic, 2008 (as adapted from Kahneman & Tversky, 1973):

> *In a study 1000 people were tested. Among the participants there were 996 managers and 4 firemen. Don is a randomly chosen participant of this study. Don is 27 years old. All his friends consider him very brave and strong, and in relatively good physical shape. He goes to the gym regularly. What is the probability that Don is a manager? Please answer using BELIEFS (or alternatively – Please answer using STATISTICS)*

Conflict (incongruent) problems, as illustrated above, are those in which the presented *base-rates* and description dictate opposing responses; non-conflict (congruent) problems are those in which the base-rates and description support the same response. In the conflict problem illustrated above, when instructed to respond under the belief instruction, the appropriate response would be about 0% probability that Don is a manager. According to serial models (e.g., default interventionist model) of traditional dual process theories, when responding under the "statistic" instruction, one must override and inhibit an intuitive answer cued by the compelling description to respond with 100% probability that Don is a manager.

The associations we make over time tend to activate an autonomously derived decision based on prior experiences or beliefs unless the initial judgment is suppressed to allow us to further reflect and detach from contextual cues (Stanovich & Stanovich, 2010). This ability to inhibit default reactions based on generalizations from prior experience or beliefs is an executive function that is highly reliant on inhibitory control (De Neys, Schaeken, & d'Ydewalle, 2005; Stanovich & West, 2000). Traditional base-rate problems such as those illustrated above are ideal for studying executive inhibitory processes because the reasoner is forced to inhibit one source of information over another to produce an appropriate response according to the response instruction. Given the difficulties in executive functioning associated with ADHD (Barkley, 1997a, 1997b) it seems reasonable to explore whether well-evidenced deficits in inhibitory control for individuals with ADHD hinder their reasoning performance.

This thesis examines the relationship between ADHD, reasoning performance, and executive inhibitory control. One way of doing this is by having participants with ADHD and their non-ADHD counterparts solve belief/probability tasks that are assumed to require the activation of executive inhibitory processes to suppress one of two conflicting responses. A discussion will follow providing insight into the comparative reasoning performance by the two groups. Findings of this research can better inform educators, psychologists, and researchers on *how* to help students with ADHD learn more efficiently and successfully. Interventions that provide strategic training to advance reasoning skills and the provision of extra time to activate hypothetical reasoning may supply mental reasoning tools and promote skills to prevent cognitive overload. This may enhance development of neural reasoning networks in students with ADHD (Posner & Rothbart, 2005), increase overall academic achievement in the classroom, and improve performance on intelligence tests (Naglieri, Salter, & Edwards, 2004).

Thesis Organization

Chapter Two begins with a general overview of ADHD outlining the dominant theory associated with the disorder, a discussion of the executive functions shown to manifest deficits in

ADHD and a literature review that supports conclusions of executive impairments associated with the disorder. The theoretical framework of the dual-process theories of reasoning in decision-making (analytic-based reasoning and belief-based reasoning) will follow. The conclusion of Chapter Two highlights the apparent lack of research regarding ADHD and the link to possible deficits in applied reasoning for those with the disorder. Chapter Three will provide the reader with a detailed plan of the study's research methods and results of the statistical analyses. Chapter Four will provide the discussion, implications, practical, limitations, future studies, and concluding remarks.

Borrowing from De Neys (2012), some general clarifications are provided relating to the nomenclature applied to this thesis. For the sake of simplicity, the overarching term of ADHD was used when discussing the dominant model of ADHD-C, the focus of this paper, unless specifically differentiating between subtypes. Traditional labeling of responses as "incorrect" or "biased" is somewhat of an over simplistic appraisal of responses, as authentic measures of normative accuracy are much more complex and subject to inferences derived from Bayes' theorem connecting conditional probabilities to their inverses (Evans, 2010). This is an exercise in probability calculus that is very much beyond the scope of this paper. For the sake of simplicity and consistency, the terms "correct," "*normative*," or "logical" are used as general terms to refer to responses based on formal rules by which information should be measured and judged (Elqayam & Evans, 2011). Additionally, the term "logical" is used as a general description to refer both to standard logic and probability theory in problem-solving.

Definition of Terms

Attention deficit disorder (ADD)	First designation used in DSM-III (APA, 1980) to highlight attentional impairments as the central feature of disorder.
Attention deficit/hyperactivity disorder (ADHD)	Name changed in DSM IV (APA, 2000). A mental illness usually beginning in childhood, consisting of symptoms of inattention, impulsiveness, and hyperactivity that are inappropriate for the child's age (APA, 2013).
Base-rate	The statistical probability of an event occurring without further intervention (Reyna, 2004).
Base-rate neglect	The tendency to undervalue statistical information in favour of stereotypical descriptions (Bar-Hillel, 1980).
Behavioural inhibition	See inhibitory control.
Behaviour self-regulation	The ability to monitor and control our own *behaviour,* emotions, or thoughts, altering them in accordance with the demands of the situation (Barkley, 1997a).
Belief bias	The tendency to judge conclusions according to belief, regardless of validity (Thompson, 2013).
Cognitive bias	See belief bias.
Conflict detection	In base-rate problems: Awareness that a stereotypical description cues a response that conflicts with the response based on the analytic base-rate information (De Neys & Glumicic, 2008).
Decontextualized reasoning	To reason logically from premises irrespective of their content (Moshman & Franks, 1986).
Disinhibition	A lack of restraint manifested in disregard for social conventions, impulsivity, and poor risk assessment (Barkley, 2012)

Disinhibition theories	A primary executive inhibition deficit in ADHD leads to a cascade of downstream problems in behaviour regulation, such as arousal regulation, working memory, and the dysfunction of other regulatory domains (Barkley, 1997a)
Dopaminergic hypothesis	Executive deficits in ADHD are linked to abnormalities with the brain's production and/or release of the neurotransmitter dopamine (Levy, 1991).
Executive functioning	An umbrella term to describe a variety of processes commonly assumed to play a role in higher level cognitive operations (Barkley, 2012); a particular set of components (variously termed "executive processes," "executive routines," "control processes," "metacomponents," or "executive functions") that exert superordinate control over the brain's computational programs (Sternberg, 1985).
Executive inhibition	See inhibitory control.
Heuristic bias	See belief bias.
Heuristic response/judgment	Response guided by a mental shortcut rather than using more analytic procedures (Evans, 2006).
Intuition	Immediate apprehension by the mind without the intervention of reasoning (Evans, 2010).
Intuitive judgment	Those judgments that are arrived at by an informal and unstructured mode of reasoning without the use of analytical methods or deliberative calculation. (Kahneman & Tversky, 1982).
Inhibitory control	A forerunner of executive functions that sets the stage for proficient performance of other executive functions and command a range of mechanisms that function to inhibit irrelevant cognitive associations, suppress inappropriate or prepotent responses, defer responses to a more appropriate time, or resist interference from irrelevant stimuli that may disrupt the goal at hand (Barkley, 1997a).

Logical response	See normative response.
Metacognition	The individual's own awareness and consideration of his or her cognitive processes and strategies. The uniquely human capacity of people to be self-reflexive, not just to think and know but to think about their own thinking and knowing (Flavell, 1979).
Mind, brain, and education science (MBE)	Brain-based educational pedagogy that is spurring a radical shift in how we think about education and how we teach our students (Tokuhama-Espinosa, 2011).
Mindware	The rules, knowledge, procedures, and strategies that a person can retrieve from memory to aid in decision-making and problem-solving (Perkins, 1995).
Normative response	Responses based on formal rules by which information should be measured and judged (Elqayam & Evans, 2011).
Rationality	Open minded thinking disposition that consistently uses reason or logic in thinking out a problem in accordance with normative principles (Stanovich, 2009)
Response Inhibition	See inhibitory control.
Salience effect	Argument weight, or statistical probability, is often overlooked in favor of salient, compelling descriptions that cue flawed judgments (Kahneman & Tversky, 1973).
Selective attention	Attention that allows one to focus on a single stimulus and block distracters (Wiig, 2011).
Self-regulation	Self-regulation represents both effortful and, in some models, involuntary mechanisms that allow behaviour to be adapted appropriately to a changing context (Logan, 1994)
Sustained attention	Attention that is maintained over time and is controlled (Wiig, 2011)
Traditional base-rate problem	Reasoning problem in which the stereotypical description conflicts with presented base-rates and prompts differing responses (Evans, 2006).

Type 1 Reasoning Processes	Cognitive processes correlated with rapid thinking and delivering an autonomously produced correlated with prior experiences or beliefs (Evans & Stanovich, 2013).
Type 2 Reasoning Processes	Cognitive processes correlated with slower, more deliberate thinking that is effortful and highly dependent on working memory (Evans & Stanovich, 2013).
Working memory	A neural activation resource of limited capacity and duration that serves to maintain and manipulate mentally represented knowledge for short periods of time (Wiig, 2011).

CHAPTER 2
LITERATURE REVIEW

This chapter includes a critical review of the literature related to ADHD and dual process theories of reasoning. The literature review is divided into four sections. The first section provides an overview of ADHD along with data on prevalence, etiology, differentiation of subtypes, biological underpinnings, and comorbidity of ADHD. The second section overviews Barkley's (1997a, 1997b) theoretical conceptualization of the underlying factors associated with ADHD relating to disinhibition. This is followed by a review of the evidence that supports a core deficit of executive response inhibition in ADHD. The third section discusses dual process theories of reasoning with a focus on the serial model of reasoning; specifically, the default interventionist account of reasoning. Finally, this chapter concludes with an overview of the current study, the two experimental tasks used in the study, and the expected hypotheses.

Overview of ADHD

The essential feature of ADHD is currently described as a "persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development to a degree that is inconsistent with normal development," (APA, 2013, p. 59). The diagnostic criteria for ADHD in the DSM-5 (APA, 2013) contain five parts, A through E (see Table 2). Part A contains 18 distinct diagnostic symptoms of both inattention (A1) and hyperactivity-impulsivity (A2), of which six or more must have persisted for at least six months. Part B requires that symptoms be present before age 12. Part C requires that impairment must be present in two or more settings; D stipulates the requirement for "clear evidence that the symptoms interfere with, or reduce the quality of, social, academic, or occupational functioning" (APA, 2013, p. 60). Finally, Part E requires that symptoms do not occur exclusively during the course of other mental health conditions. If both criterion under A1 (inattention) and A2 (hyperactivity- impulsivity) are present, a diagnosis of ADHD Combined Presentation (ADHD-C) is indicated. If only the criterion for inattention (A2) has been met, a diagnosis of ADHD Predominantly Inattentive Presentation (ADHD-I) is specified. If only the criterion for hyperactivity- impulsivity (A2) has been met, a diagnosis of ADHD Predominantly Hyperactive/ Impulsive Presentation (ADHD-H) is specified. The latter type, ADHD-H , often arises in the preschool years, typically at ages 3 to 4 years (Applegate et al., 1997) and rarely occurs beyond six years of age (Nigg, 2005, Willcutt et al., 2012). Thus, it is unclear whether ADHD Predominantly Hyperactive-Impulsive presentation (ADHD-H) is really distinct from the ADHD Combined Presentation (ADHD-C) or simply an earlier developmental stage of it (Nigg & Barkley, 2014). The combined subtype, ADHD-C represents the classic ADHD profile, characterized by impulsiveness and high activity levels as well as poor focused attention (mind off task, easily distracted, inability to concentrate). ADHD-C has an onset within the first few grades of primary school (ages 5-8; Hart, Lahey, Loeber, Applegate, & Frick, 1995), likely owing to the prerequisite that both hyperactivity and inattention be present to diagnose this subtype. The inattentive subtype of ADHD-I appears to emerge a few years later (ages 8-12) than the other types (Applegate et al., 1997) and appears to have a different biological mechanism of activation, leading some researchers to argue that it may be a different disorder altogether (Barkley, 2001, 2006; Carr et al., 2010; Milich et al., 2001).

Adults identified as ADHD by this interview also have been shown to have significant deficits in measures of inattention, inhibition, and working memory and to be impaired in numerous domains of major life activities in this and prior projects (Barkley and Murphy, 2006, Barkley et al. 2008; Fischer et al. 2004; Murphy et al. 2001).

Prevalence. The prevalence of ADHD is at least as high outside of North America as it is in North American children, with the highest prevalence rates being seen when using DSM-IV diagnoses (Faraone, Sergeant, Gillberg, & Biederman, 2003). The most accurate estimations come from recent large-scale studies. One meta-analysis of worldwide prevalence studies reported an average of 5.5% of children as having ADHD (Polanczyk, Silva de Lima, Horta, Biederman, & Rohde, 2007), while an epidemiological study of U.S. adults as well as a worldwide prevalence study placed the prevalence at 3.4 to 4.4% (Fayyad et al., 2007; Kessler, Berglund, Demler, Jin, & Walters, 2005). Increasing rates (Visser, Bitsko, Danielson, Perou, & Blumberg, 2010) are likely fueled by increasing awareness of symptoms among educators and parents, greater transfer of knowledge from the scientific community to medical professionals (Goldstein & Naglieri, 2008), as well as the broadening of diagnostic criteria to include more subgroups (APA, 2013). Thus, more individuals are referred, diagnosed, and treated.

Etiology. Considerable research has accumulated on various etiologies for ADHD (Barkley, 2006; Nigg, 2006). Notably, virtually all of this research pertains to the Combined Type of ADHD –C as ADHD-I, the subset associated with a sluggish cognitive tempo, is likely qualitatively different disorder. But for ADHD-C, findings are unequivocal that, while ADHD may have multiple etiologies, neurological and genetic factors likely play the greatest role in causing this disorder (Barkley, 2006; Nigg, 2006). Family and adoption studies provide unmistakable evidence of the genetic component in ADHD (Biederman et al., 1992; Faraone & Biederman, 1998). With a heritability rate of just under 80% (see Figure 1), ADHD is more heritable than asthma, breast cancer, and schizophrenia (Faraone & Biederman, 1998). It is important to note that, although research strongly implicates neurobiological and genetic factors in ADHD, environmental and social factors can alter the trajectory of the disorder. Factors such as parental training programs and academic interventions for ADHD students may mitigate negative outcomes thought to be attributable to ADHD (Loe & Feldman, 2007; Sonuga-Barke, Daley, Thompson, Laver-Bradbury, & Weeks, 2001).

The common neurological pathway through which these causes produce their effects on behaviour has become evident from converging lines of research that use a broad array of assessment tools, including neuropsychological tests of frontal lobe functioning, electrophysiological measures (electroencephalogram, quantitative electroencephalography, event-related potentials), measures of cerebral blood flow, and neuro-imaging studies using positron emission tomography (PET), magnetic resonance imaging (MRI), and functional MRI. Numerous studies have used neuropsychological tests of frontal lobe functions (see Table 1) to uncover executive functioning deficits (for a review, see Barkley, 2006). Consistent results suggest that poor inhibition of behavioural responses, or executive inhibition (Nigg 2001, 2006) is impaired in this disorder, at least for ADHD-C. Possible neurotransmitter dysfunction or imbalances have been proposed in ADHD for quite some time (for a review, see Sagvolden, Johansen, Aase, & Russell, 2005). Neurochemical abnormalities that may underlie this disorder suggests involvement in at least three systems, these being dopaminergic, noradrenergic, and serotonergic, which mediate attention and concentration (dopamine), sleep, aggression, and irritability (serotonin), and alertness, adrenaline levels, and fight or flight reactions (norepinephrine). As frontal brain regions are rich in dopamine, dopamine may be an important link for understanding ADHD pathophysiology. There exists substantial support for the dopaminergic hypothesis that identifies dysregulation in the dopamine system as an underlying origin of ADHD (Genro, Kieling, Rohde, & Hutz, 2010) because of the assumed dopamine agonistic action of stimulant drugs (Biederman & Faraone, 2002; Castellanos, 1997; Castellanos et al., 2002; Johansen et al., 2002). However, as with all psychopathologies, research conclusions are largely based on correlational findings, prohibiting claims of direct causality.

The DSM-5 (APA, 2013) notes that for persons with ADHD, academic or work performance is often impaired, even in the absence of a specific learning disorder. Although the DSM -5 makes a reference to involvement of cognitive processes for inattentive behaviour, the diagnostic criteria in the DSM-5 continue to underscore behavioural, rather than cognitive or neuropsychological dysfunctions, allowing for considerable latitude for clinical judgement in the diagnosis of ADHD. Efforts to obtain a cognitive profile of ADHD as a reliable means of assessment using traditional psychometric measures of intellectual ability or a variety of neuropsychological measures has been elusive thus far (Jurado & Rosselli, 2007; Goldstein & Naglieri, 2008). The high rate of comorbidity with ADHD (Barkley, 2006) conditions makes differential diagnosis and treatment a complex process. Cognitive mapping of ADHD profiles is an important area of research as identifying the cognitive processes associated with ADHD may help with diagnosis and also facilitate the design of effective educational interventions.

Comorbidity and ADHD. Executive functioning deficits specific to ADHD are not like a fracture where it can be diagnosed like an x-ray (Brown, 2008). The task of sorting out organizational roles of executive functions is often complicated by comorbid learning disorders or psychiatric conditions. Elevated levels of comorbid externalizing behaviours (conduct problems, aggression) and internalizing disorders (anxiety, depression) symptoms are associated with greater ADHD symptom severity, emphasizing the need for early intervention. Kessler et al. (2005) reports that adults with ADHD are more than six times as likely to have one or more comorbid psychiatric conditions at some time in their life, with two of the most frequent being oppositional defiant disorder and anxiety disorders (Adler, Barkley, Newcorn, Spencer, & Weiss, 2007), which reflects the lifelong impact of the condition.

The overlap of anxiety disorders with ADHD has been found to be 10% to 40% in clinic-referred children, averaging to about 25% of children to over one third of adolescents and even higher in adults (Adler et al., 2007; Barkley, 2006; Biederman, Newcorn, & Sprich, 1991; Tannock, 2000), with about 50% of those cases developing before age 6 years (Adler et al., 2007; Brown, 2000; Jensen et al., 2001; Mayes et al., 2009; Merikangas, Nakamura, & Kessler, 2009). More common to ADHD are learning disabilities. Children with ADHD have a significantly higher rate of learning disabilities than children without ADHD, with rates as high as 70% documented in children referred for ADHD (Mayes, Calhoun, & Crowell, 2000). Of this, disabilities in math, reading, and spelling are recorded at about 30% for each of these areas; however, the overall prevalence for a learning disability doubled to that of 70% when a learning disability of written expression was accounted for (Mayes et al., 2000).

Biological Underpinnings of ADHD. Researchers have been studying cognitive impairments associated with ADHD using cognitive tests originally developed by neuropsychologists to evaluate frontal lobe functioning from stroke, schizophrenia, or traumatic brain injury. Many executive function tests have been utilized to assess important cognitive management functions in the prefrontal cortex where the brain's executive system is thought to be located (for a review see Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; see also Barkley, 2006). As increasing numbers of research studies documented that individuals with ADHD performed poorer than non-ADHD controls on these measures of executive function, researchers began to describe ADHD as a neuropsychological disorder of executive functioning (for a review, see Dickstein, Bannon, Castellanos, & Milham, 2006). Although the definition of executive function is still evolving, most researchers agree that the designation refers to neural circuits that prioritise, integrate, organize, and regulate other cognitive functions (Brown, 2006). Thus, the brain's executive system is assumed to provide an instrument for self-regulation (Vohs & Baumeister, 2004). Even with executive function tests specifically designed to isolate operative areas of inhibitory control or working memory, the brain's complex and dynamic integrated management of neural circuits makes it difficult to pinpoint precise functions of key executive components. Moreover, neural networks are not created equally and they do not function in isolation – some neural networks have integrated operations, others manage subordinate networks. For example, various neural networks in the prefrontal cortex, limbic region, and cerebellum collectively function to organize and manage executive components (Fisher et al., 2002). It is the dynamic and integrated operation of the brain as a whole that the current study is most interested in and reflects the research question for this paper. How do students with ADHD think, reason, and make judgments on complex logic problems that might be similar to those given in a classroom setting? Understanding how individuals with ADHD perform cognitively in a classroom setting when problem-solving will assist with creating a cognitive profile for ADHD, which can help to inform interventions for improved classroom learning.

Differentiating Symptoms of ADHD Subtypes. ADHD-I is characterized as a failure of appropriate cortical arousal and directed or selective attention (Naglieri, 2005). Children with ADHD-I have impairment in selective attention and may appear day dreamy, hypoactive, lethargic, and even withdrawn (Barkley, 1997a). When a multidimensional stimulus array is presented to a person who is then required to pay attention to only one dimension, the suppression of response to more salient stimuli and the allocation of attention to the central target rely on the resources of selective attention and arousal. Those with ADHD-C have significant deficits in behavioural inhibition and inattention (the executive functions) that are critical for effective self-regulation (Barkley, 1997a; for a review, see Nigg & Barkley, 2014). This is best exemplified by the account of a child who can focus for length periods on a stimulating computer game but has considerable trouble staying on task during a monotonous or uninteresting classroom assignment. The ADHD-C child can attend to the computer game because ADHD-C is characterized as lacking in behavioural control not attention, whereas ADHD-I is characterized as having a failure of selective attention. Such a differentiation is important to recognize and appreciate, particularly when designing classroom interventions to support ADHD.

Children with ADHD-C are considered to have poor behavioural inhibition (Nigg & Barkley, 2014). This can be manifested in, for example, problems with inhibition of dominant, but erroneous responses leading to impulsive decision-making, rash judgments, impetuous actions or verbal responses, poor planning, foresight, and anticipation, reduced sensitivity to errors, poor implementation of structure and organization, impaired verbal problem-solving and self-directed speech, poor rule governed behaviour, poor self-regulation of emotion, problems developing, using, and implementing organizational strategies, and difficulties with self-regulation and inhibition (Nigg & Barkley, 2014). Thus, it is not surprising that increasingly ADHD is not seen as a disorder of attention at all, rather as a disorder primarily of self-regulation. Indeed, Barkley (1997a, 2001) concludes that ADHD-I could be considered a separate disorder from that of ADHD to differentiate the specific cognitive impairments: deficits in attentional performance in ADHD-I and impairment of self-regulation in ADHD-C. In attempts to understand the origin of ADHD-C, researchers and clinicians have shifted their research from attention to that of disinhibition (Barkley, 1997a; 1997b; Douglas, 1999; Pennington & Ozonoff, 1996, but for a review see Nigg & Barkley, 2014). Executive inhibition refers to the deliberate suppression of a prepotent, yet task-inappropriate response in order to protect other responses deemed necessary for the service of a distal goal in working memory (Nigg, 2003). This process is deliberate, requires cognitive resources, and occurs with relatively low fear or anxiety (i.e., suppression of a response not motivated by fear or anxiety).

Disinhibition Theories of ADHD

Disinhibition theories, as applied to ADHD, offer a parsimonious, integrative, and testable theory of the core origin of dysfunction in ADHD (Nigg, 2001), and has been the focus of much research in recent years. One basic account of the disinhibition theory, as represented by Barkley (1997b, 2010) and Schachar, Tannock, and Logan (1993), suggests a primary executive inhibition deficit in ADHD leads to a cascade of downstream problems in behaviour regulation, such as arousal regulation, working memory, and the dysfunction of other regulatory domains (see illustrative model, Figure 2). Disinhibition theories almost exclusively refer to the combined type of ADHD, which encompasses characteristics of inattention, hyperactivity, and impulsivity (Barkley, 1997b, 2010; Pennington, & Ozonoff, 1996; Quay, 1997; Schachar et al., 1993), while the inattentive subtype, ADHD-I, is mainly associated with selective attention problems (Barkley, 2001; Goldstein & Naglieri, 2008). Several reviews have concluded that executive dysfunction, particularly behavioural inhibition as defined through disinhibition theories, is a primordial component in ADHD (Barkley, 1997b, Pennington, & Ozonoff, 1996; Schachar et al., 1993).

Predictably, our increased scope of understanding of ADHD as well as the heterogeneity of the population diagnosed with the disorder has generated many theories on the putative causes the disorder. Competing models from theorists who disagree on the primacy of an inhibitory deficit emphasize other factors as principal moderators of performance, such as activation, focus, effort, emotion, and memory (Brown 2005, 2006), arousal activation and effort (Sergeant, 2000; Sergeant, Oosterlaan, & Van der Meere, 1999), alertness /vigilance systems (Swanson et al., 1998), delay aversion (Sonuga-Barke, 2005), self-regulation (Douglas, 1999), cognitive and affective control (Nigg & Casey, 2005), and reinforcement and motivation (Sagvolden et al., 2005). Their discussion is beyond the scope of this paper, the focus of this study being on the more dominant theories of ADHD that specify impairment of executive inhibition as a primordially controlling factor of executive function and a core neurocognitive dysfunction specific to the combined type of ADHD (Barkley, 1997b; Schachar et al., 1993).

Extant literature converges on the broad domain of executive function as the major area of impairment (Barkley, 1997b; Pennington & Ozonoff, 1996), centering on the primacy of executive inhibition to control a wide range of complex executive functions and behaviours, a conclusion that continues to receive empirical support (Bayliss & Roodenrys, 2000). The basic principle of this executive model of behaviour inhibition is that suppression of prepotent response is essential for self-regulation (Logan, 1994). Self-regulation represents both effortful and, in some models, involuntary mechanisms that allow behaviour to be adapted appropriately to a changing context. Thus, complex actions and higher level cognition, including social behaviour, response inhibition, planning, skilled motor behaviour, appropriate delay, and language production, all hinge on effective executive (inhibitory) control (Nigg, 2001) and are necessary for higher-order behaviours such as working memory (for avoiding extraneous information), goal-directed behaviour (important for delayed gratification), and emotional self-control (for minimizing emotionally laden reactions; Barkley, 1997b, Quay, 1997). This study focuses on this primary deficit of inhibition associated with ADHD; in particular, response inhibition and the ability to suppress a prepotent response when solving problems in which inhibition of beliefs mediates normative performance.

Nigg (in press, as cited in Eme 2015) discusses inhibition failures from a theoretical model that aligns well with claims from theorists of dual processes of reasoning. Specifically, Nigg describes two types of inhibitory failures that stem from either bottom-up or top-down regulatory processes and their respective neural connections. Type 1 (bottom-up) processes are functionally connected to subcortical brain areas (basal ganglia, limbic system, thalamus, hypothalamus, and cerebellum) and are thought to be automatic, reactive, and reward motivated (Nigg, in press, as cited in Eme 2015). Flawed decision-making associated with these Type 1 reward-based processes is assumed to stem from temporal discounting (also known as delay discounting) of rewards motivated (Nigg, in press, as cited in Eme 2015). In this scenario, poor immediate rewards are impulsively chosen over superior, but delayed, rewards due to the dominance of reward-driven Type 1 regulatory processes.

The second model of inhibitory failure is driven by Type II (top-down) processes, served primarily by the prefrontal cortex and the anterior cingulated cortex and their connections to other cortical and subcortical areas (Nigg, in press, as cited in Eme, 2015). As with Type 2 processes of reasoning, these Type II executive control processes are correlated with more effortful, deliberate, goal motivated behaviours. Faulty decision-making associated with Type II regulatory processes is thought to stem from a failure of Type II executive processes to over-ride stimulus-triggered responses (Nigg, in press, as cited in Eme 2015) so as to allow regulation of focus and behaviour.

Regardless of the origin of inhibitory deficits, when inhibitory control is deficient, the ensuing behaviour encompasses a wide range of inappropriate impulses and motor actions. This executive model of behaviour inhibition can account for both impulsive–hyperactive and inattentive behaviours in the ADHD combined type (Barkley, 1997b). The explanatory appeal of an executive behaviour inhibition deficit relating to the most obvious ADHD symptoms is compelling. Without a proper functioning mechanism to delay or prohibit a prepotent response, the possibility of thoughtful, appropriate goal-directed behaviour in a situation is greatly diminished, if not impossible. Executive functions of inhibition underpin reasoning abilities, problem-solving, and planning abilities that are crucial to the successful accomplishment of future goals (Barkley, 2015; Diamond, 2013) and are of critical importance for successful functioning in social and academic, and occupational domains (Diamond, 2013).

Evidence for Disinhibition Theories. There is little doubt that poor behavioural inhibition plays a central role in ADHD (for reviews, see Barkley, 1997a; Nigg, 2001). Research into executive functioning using classic executive function tasks (see Table 1 for descriptions) may be the most well-developed area of research in ADHD and more contemporary fMRI studies have literally provided us with an improved picture of the neurobiological deficits related to the ADHD brain (Cortese et al., 2012; Hart, Radua, Nakao, Mataix-Cols, & Rubia, 2013).

Further research has supported the conclusion that response suppression is the primary origin of executive function deficits in ADHD. Data from studies of executive function tasks (for a review, see Nigg, 2005) provide convergent evidence of a deficit in response inhibition (in contrast to sensory, input, or cognitive inhibition) and link ADHD to difficulties with response output suppression during the late stage of processing (Nigg, 2001). Strong support for an executive inhibitory deficit comes from experimental studies using the non-motivational go/no-go task (Table 1). This task creates a dominant response set by making most trials “go trials.” The dominant response must be subsequently withheld on the comparatively rare “no-go trials.” The ability to interrupt an about-to-be-executed response requires activation of the right inferior frontal cortex (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003), as well as regions in basal ganglia, including the caudate nucleus (Casey, Tottenham, & Fossella, 2002). Extensive neuroimaging data support the preferential involvement of inferior regions of dorsolateral prefrontal cortex on the no-go versus the go trials, using both block designs (participants alternate between "go" responses on every trial and a proportion of "no go" trials; Casey et al., 1997; Vaidya et al., 1998) and trial-by-trial event-related fMRI methods (varying trial formats are pseudo-randomly interspersed; Konishi et al., 1999). Recordings by electroencephalogram and magnetoencephalogram also indicate frontal activation on the no-go versus the go trials (e.g., Yong-Liang et al., 2000). More specifically, in fMRI studies with children and adults without ADHD, Casey and colleagues (1997) found more activation in the anterior cingulate cortex for those that had the most difficulty with the no-go trials, suggesting that difficulty of the response conflict causes activation in the anterior cingulate cortex to monitor the conflict. This aligns with similar neuroimaging findings of *conflict detection* studies relating to the loci involved in reasoning and decision-making (see De Neys, 2012 for a review). Casey et al. (1997) also observed greater activation in the orbito-prefrontal cortex (but not in the anterior cingulate) for those making the fewest false alarm errors, suggesting that this brain area is involved in inhibiting the inappropriate response.

Altogether, these neuroimaging data provide converging evidence that a separate inhibitory process is required for behavioural suppression in the no-go trials and that the ability to inhibit on no-go trials depends on specific regional activation in the prefrontal cortex (Nigg, 2001). Notwithstanding the evidence, the go/no-go task has been criticized for not functionally isolating inhibition. Specifically, critics argue (e.g., Schachar et al., 1993) it is possible that failure to withhold a response on the no-go trial could be accounted for by strong prepotent go processes (i.e., strong environmental stimuli), not disinhibition. This argument has also been presented by Nigg (in press, as cited in Eme 2015) – is inhibitory dysfunction due to a failure of Type II regulatory executive processes to successfully inhibit Type I reward-based processes, or alternatively, are poor immediate rewards impulsively chosen over superior but delayed rewards due to the dominance of reward-driven Type 1 regulatory processes?

The best evidence for a deficit in response inhibition comes from studies of the stop task, (Logan & Cowan, 1984), which has amassed extensive empirical and theoretical support as a measure of deliberate suppression of a motor response. At least 15 studies have now been reported for using the stop task as a valid measure of executive inhibitory control in ADHD, or lack thereof (see Nigg, 2001), even when controlled for comorbid oppositional and conduct disorders (Dimoska, Johnstone, Barry, & Clarke, 2003; Nigg, 1999; Rubia, Oosterlaan, Sergeant, Brandeis, & Leeuwen, 1998; Schachar, Nita, Logan, Tannock, & Klim, 2000). Moreover, in addition to a large deficit in response inhibition, stop task studies have noted smaller deficits in slow and variable response output (Nigg, 1999; Oosterlaan, Logan, Sergeant, 1998). This is noteworthy, because it emphasizes the point that it is unlikely excessively strong stimuli that are contributing to inhibition difficulties (otherwise the response would be rapid). This further complicates the notion of inhibitory dysfunction as a primary deficit, as slow response speed could be due to poor vigilance or activation. Accordingly, the data may suggest an additional or secondary deficit, perhaps in vigilance or sustained attention (Parasuraman, Warm, & See, 1998), arousal (Losier, McGrath, & Klein, 1996), or activation (Tucker & Williamson, 1984), complicating the interpretation of where the dysfunction originates from in the executive system.

Dual Process Theories of Reasoning

Human thinking can be characterized by two qualitatively different streams of processing that operate within a dual-process system of reasoning (Evans, 2003, 2008, 2009; Evans & Over, 1996, 2004; Kahneman & Frederick, 2002, 2005; Sloman, 1996; Stanovich, 1999, 2004; Stanovich & West, 2000). Dual process theories of reasoning are numerous – Stanovich (2004) identifies over 20 distinct theories – and all have subtle differences to explain the operational format and interplay between the two systems; however, they are similar in that they all describe the two types of processing as either autonomous or non-autonomous. Type 1 processes are low in computational power but have the advantage that they are low in cost. The defining feature of Type 1 processes is their autonomy (Thompson, 2013), considered autonomous because (a) they discharge rapidly, (b) their discharge is obligatory when cued by appropriate stimuli, (c) they do not use valuable cognitive resources (e.g., working memory), (d) they do not require conscious awareness attention or effort to execute, (e) they do not depend on resources from central executive control systems, and (f) multiple Type 1 processes operate in parallel without interfering with each other (Stanovich & Stanovich, 2010). Type 1 processes are correlated with *heuristic judgments* (i.e. mental shortcuts) derived from self-contained experiences and beliefs that are delivered "prêt-à-porter" (ready-made) to our stream of conscious awareness (Evans & Stanovich, 2013). Alternatively, the non-autonomous Type 2 processes are deliberate and require effortful activation to facilitate decontextualized, *hypothetical reasoning* based on logic and *rationality* (Evans, 2003). According to the default interventionist account of dual process theories, Type 1 processes form a default response unless there is active and deliberate intervention from methodical, explicit Type 2 processes to inhibit and override the Type 1 outputs (Thompson, 2013). As analytic reasoning must be deliberately engaged to override the quicker belief-based appraisals, it is assumed that slower, more methodical evaluations do not interfere with the swift heuristic responses based on prior experience (Evans & Stanovich, 2013). However, the autonomous and faster belief-based reasoning processes are readily able to interfere with slower, more rational mental operations (Thompson, 2013). Thus, only one-way interference, not two-way, should occur, which may result in conflicting outputs that compete to provide a final judgment.

Reflective thought derived from Type 2 processes is mentally taxing and limited to single tasks at a time (serial processing), making it an undesirable choice for everyday reasoning (Evans, 2010). Humans are cognitive misers and tend towards the most efficient cognitive strategies permissible, sometimes at the expense of accuracy (Evans, 2010; Stanovich, 2009). Thus, intuitive Type 1 processes dominate as a labour-saving means for routine decisions and judgments. There are many cases in which these mental shortcuts provide us with the necessary ability to make judgments quickly and efficiently (Gigerenzer, 2007), and, without a doubt, these quick-thinking skills are needed for survival. However, an over-reliance on implicit Type 1 processes can be a “false friend” (Evans, 2010, p. 315). Although intuitive processing is a quick and effective means of reasoning, it more often than not reflects biased or irrational judgments (Evans, 2010, Stanovich, 2003), especially in unfamiliar territory or when dealing with novel problems or situations.

A wealth of research has demonstrated that participants tend to strongly favor the stereotypical information over the base-rate probability because (a) the stereotype is the more intuitive source of information (see Barbey & Sloman, 2007 for a review) and (b) base-rate evaluation is assumed to require more effortful Type 2 processing (Barbey & Sloman, 2007; Kahneman & Tversky, 1973; Sloman, 1996). Dual process theorists (Evans, 2003; Sloman, 1996; Stanovich, 1999; Thompson, 2013) use the temporal asymmetry between the two systems to explain the phenomenon of *base-rate neglect*, the tendency to undervalue statistical information in favour of stereotypical descriptions (Bar-Hillel, 1980). The problem is the *salience effect* (Kahneman & Tversky, 1973). Argument weight, or statistical probability, is often overlooked in favor of salient, compelling descriptions that cue flawed judgments, resulting in a *belief bias* (the tendency to judge conclusions according to belief, regardless of validity; Thompson, 2013). When solving conflict problems that intuitively cue a flawed belief response that directly conflicts with logic, the erroneous judgment must be overruled and inhibited by more deliberate processes (De Neys, 2012; Evans, 2010; Thompson, 2009; Evans & Stanovich, 2013). This can be difficult, as our *intuitive judgments* are often convincing and align with past experience, beliefs, or knowledge (Thompson, 2009). Specific instructions emphasizing the necessity for logical responses reduce the belief bias effect, but do not eliminate it (Evans, 2003). For example, a strong but undesirable, intuitive response can sometimes dominate over a less obvious, but normative, logical response. Examples can often be found in conflict syllogisms, in which a conclusion is logically valid but the premise is unbelievable (e.g., All mammals walk; whales are mammals; therefore whales can walk; Stanovich & West, 2000).

The ability to separate logic from belief is described as *decontextualized reasoning* (Stanovich, 1999, 2003). Decontextualization skills are considered essential to higher-order cognitive abilities of reasoning and judgment (Evans, 2003; Handley, Capon, Beveridge, Dennis, & Evans, 2004). An increasing research emphasis is targeted at the inhibitory role of the brain's executive system to suppress the default Type 1 responses and adopt a higher level of thinking. Certainly we know that a compromise in our ability to engage executive processes of inhibitory control will impair our capacity for rational, systematic reasoning (De Neys, 2012; Evans, 2003; Handley et al., 2004). Even in healthy older adults, a reduction in executive inhibitory control has been shown to diminish performance in logical reasoning (Christ, White, Mandernach, & Keys, 2001). De Neys, Vartanian, and Goel's (2008) neuroimaging study of conflict detection, which monitored brain regions thought to be associated with conflict detection (anterior cingulate) and response inhibition (right lateral prefrontal cortex), concluded that *heuristic bias* can be attributed to a failure of the executive inhibitory control mechanism. When this premise is considered vis-à-vis ADHD and the inhibitory deficits associated with this disorder, it seems reasonable to suggest that deficits of inhibitory control strongly evidenced in ADHD may result in diminished performance analytic reasoning for individuals diagnosed with this disorder.

Conflict Detection in Reasoning

On the assumption that rule-based (Type 2) processes operate more slowly than belief-based (Type 1) processes, the former should not interfere with the latter; accordingly, reasoners should not be sensitive to conflict. That reasoners are aware of conflict is a paradox that proponents of serial models (e.g., default interventionist model) cannot explain. The question of conflict detection in reasoning has been investigated in multiple studies using a broad range of indirect measures to challenge this assumption. In fact, both biased and non-biased reasoners demonstrate a sensitivity to conflict (for a review, see De Neys, 2012). Even studies differentiating between those participants with high cognitive capacity and those with an average cognitive capacity have concluded that both groups are implicitly aware of conflict in reasoning problems (Thompson & Johnson, 2014; Thompson, Pennycook, Trippas, & Evans, in press). Indirect evidence of conflict detection has been shown by: increased response latencies for conflict problems relative to non-conflict problems (De Neys & Glumicic, 2008; Pennycook, Fugelsang, & Koehler, 2012); increased activation of brain regions thought to regulate conflict detection while responding to problems with mismatched information (De Neys et al., 2008; Goel, Buchel, Frith, & Dolan, 2000; Goel & Dolan, 2003); increased attention to critical facts in conflict problems (De Neys & Glumicic, 2008); poorer memory retrieval for target words associated with the heuristic response on conflict problems, suggesting that participants had attempted to block this information during reasoning (De Neys & Franssens, 2009); increased autonomic activation for conflict problems as demonstrated by skin conductance monitoring while solving conflict and no-conflict syllogisms (De Neys, Moyens, & Vansteenwegen, 2010); and in conflict base-rate problems, an increased tendency to re-review the paragraph with the base-rate information after participants have read the personality description (De Neys & Glumicic, 2008). This increased base-rate inspection was coupled with a better recall of base-rate information for conflict problems. Lastly, reasoning studies that incorporate a measure of confidence consistently demonstrate decreased self-reported feelings of confidence for conflict problems relative to non-conflict problems (De Neys, Cromheeke, & Osman, 2011; Thompson & Johnson, 2014; Thompson Prowse-Turner, & Pennycook, 2011).

The overall findings from studies suggest that reasoners area at least implicitly aware that their intuitively cued response violates normative considerations, but are often unable to successfully inhibit the dominant Type 1 response (De Neys, 2012). Thus, heuristic bias suggests a lack of inhibitory control in overriding the salient and tempting description rather than a lack of understanding of normative principles (De Neys & Glumicic, 2008, De Neys & Franssens, 2009). The large body of indirect evidence for implicit awareness of conflict has implications for dual-process theories. Specifically, in the serial model of dual processes theories of reasoning, how does an individual become aware of a conflict if Type 2 processes are not yet engaged? As Thompson (2009) argues, current accounts of dual-process theories of reasoning cannot account for when and to what extent analytic Type 2 processes intervene and supplant the intuitive Type 1 processes in cases of conflict.

Revisions to Dual Process Theoretical Models

Revised models have been proposed that attempt to address conflict detection issues for sequential (serial) models of dual process theories of reasoning, such as the default-interventionist model. For example, De Neys (2012) proposes a model that explains conflict detection without compromising reasoning efficiency. De Neys postulates additional Type 1 processes of "logical intuition" (De Neys, 2012, p.28) that arise automatically when faced with relatively simple logical or probabilistic principles. According to this account, two key characteristics are necessary for logical intuitions to be spontaneously processed: (a) an implicit awareness of such logic or probability learned early in life, and (b) an automatic output of this knowledge from Type 1 processes. De Neys' model allows for an initial shallow awareness of logic or probability that can be pitted against another intuitive response (e.g., beliefs) for appraisal and detection of conflict. In the event of conflict, Type 2 processes would be engaged to resolve the conflict and inhibit and override the unfavorable response.

A further claim could be made that base-rates, even extreme ones (e.g., 995 vs. 5), are not so complex so as to require the engagement of analytic Type 2 processes to analyze them (De Neys, 2007; Pennycook & Thompson, 2012; Pennycook, Trippas, Handley, & Thompson, 2014). As per the previously presented example, one only need recognize that group membership for one category (e.g., 997 managers) is greater than the other (e.g., 3 firemen), a relatively simple concept. Given this scenario, it is possible that two intuitive outputs are equally accessible for intuitive processing and comparison– one of beliefs and one of simple probability. When conflict is detected between the two intuitive response options, Type 2 processes are theoretically employed to engage in deeper thinking to resolve the conflict.

Unlike traditional default interventionist theories, both De Neys' (2012) hypothesis of Type 1 outputs of intuitive logic and De Neys' (2007) suggestion – echoed by Pennycook et al. (2014) and Thompson and Johnson (2014) – that rapid analysis of base-rates may not actually require Type 2 processing, can account for conflict detection. In both of these scenarios, autonomously produced Type 1 processes stream two outputs that can be compared and contrasted. Based on Pennycook and Thompson (2012), decisions can go either way (belief or statistic response), depending on one's worldview, knowledge, or collective experiences. More often, Pennycook and Thompson found, the stereotype belief is chosen, likely due to the human tendency to rely on previous context and learning. Thus, what is called "belief bias" is thought to be a decision based on experiential knowledge and the refusal to engage in Bayesian thinking – that is, an unwillingness to weigh new evidence (base-rates) against old evidence (experiential beliefs) and make a more informed and conversant decision.

The revised models introduced by De Neys (2007, 2012) and Pennycook et al. (2014) provided a rationale for the instruction manipulation in this current study. If, according to either supposition, two Type 1 outputs are spontaneously offered (that of intuitive belief and intuitive logic), an instruction manipulation specifying responses be made either by "beliefs" or by "statistics" will obviate confusion as to a normative answer.

THE CURRENT STUDY

The Utility of Base-rate Problems

Executive functioning tests are often considered too one-dimensional or simplistic to accurately measure the complex integrated operations of frontal lobe components (Brown, 2008; Rabbitt, 1997). Such tests violate the central assumption of the nature of executive functioning regarded as "the simultaneous management of a variety of different functional processes" (Rabbitt, 1997, p. 14). Attempts to isolate and measure specific cognitive functions, such as, for example, inhibitory control, are entirely inadequate and akin to "slicing smoke" (Horn, 1991, p. 198), or as Burgess (1997) illustrates, dissecting a fly and studying its parts to understand how it flies. Cognitive abilities are interrelated and various combinations of processes and abilities are employed to complete tasks. The complex, self-managed tasks of goal directed behaviour provides a much more revealing account of executive functioning than compartmentalized neuropsychological tests (Brown, 2006). Base-rate problems provide an ideal comprehensive test of executive functioning as one must prioritize, integrate, organize, and inhibit information to produce a "correct" answer as per the response instruction.

Traditional base-rate problems are skillfully designed to elicit two differing responses: a heuristically triggered response cued by a salient stereotypical description and a response based on probabilistic logic derived from presented base-rates (the frequency or likelihood of an event occurring without intervention; Reyna, 2004). Base-rate problems offer a "sweet spot" in probability reasoning.[2] The problems are not so difficult that they produce floor effects in solvability, but yet they are not so simple as to produce ceiling effects of skill. Of primary interest to the current study is the potential for base-rates to measure successful response inhibition of a Type 1 output to engage in Type 2 reasoning, as established by prior research (Barbey & Sloman, 2007, Kahneman and Tversky, 1973; Sloman, 1996). As applied traditional serial model accounts of dual process theories, when solving conflict base-rate problems, an unfavourable response must be inhibited and overridden to engage in further processing and produce the desired response. Although base-rate numbers certainly play a prominent role in formulating a response, the only math knowledge that is required is the ability to understand that one number is larger than another (e.g., 997 is larger than 3). Thus, these problems are ideal for this study's objective to examine the relationship between ADHD, inhibitory control, and successful reasoning.

Another factor that promotes the utility of base-rate problems is their structural similarity to math word problems that are routinely given to students in the classroom: Math word problems have a three-part structure as outlined by Barwell (2005): scenario, information and a question; (b) the information is arbitrary in relation to the scenario; and (c) they involve ambiguous use of verb tense, time and reference. In a similar form, base-rate problems also contain the attributes of scenario, (e.g., In a study 1000 people were tested, Don is randomly chosen), information (e.g., There were 996 managers and 4 pilots; Don is 36 years old, very intelligent, has nerves of steel and great eye hand coordination), and a question (e.g., what is the probability that Don is a manger?). Also similar to math word problems, base-rate problem information is arbitrary in relation to the scenario and involves ambiguous use of verb tense, time and reference. Just as teachers would holistically evaluate the decision-making process of students completing math word problem, base-rate problems attempt to understand and evaluate the reasoning process – that is, the integrated sum of cognitive functioning, not just one specific component of it – collectively put into action to make the decision.

Base-rate problems also parallel classroom-based math word problems in that both require an open approach in which students draw on several sources of information to provide a

[2] V. Thompson, personal communication, March 25, 2014

normative answer. This approach can be characterized by four main steps, as outlined by Barwell (2005): (a) understanding the problem situation; (b) mathematizing the situation; (c) conducting a mathematical analysis; and (d) interpreting and communicating results. Base-rate problems offer an added value in that they offer reasoners two pieces of information that can be manipulated to elicit opposing responses: base-rates and a luring stereotypical description. Coupled with an instructional manipulation that asks reasoners to respond either with beliefs (as cued by the stereotypical description) or to respond statistically by way of presented base-rates, these problems give researchers an ideal opportunity to study the action and interaction of the two processes thought to mediate human reasoning, Type 1 intuitive processes and Type 2 analytical processes.

ADHD and Inhibitory Control in Analytic Reasoning

The proposal that inhibition is an essential executive operation for higher-order cognition has direct implications for individuals with ADHD and their ability to successfully engage in analytic reasoning. The association between reasoning and ADHD, particularly when reasoning on complex problems that might parallel those given in a classroom setting (as opposed to using tests of executive functioning to isolate cognitive operations) is an area of research that is ripe for exploration (Handley et al., 2004) and that, up till now, has had limited investigation, if any. It is possible that primary deficits of inhibitory control in ADHD, as outlined by disinhibition theories, would substantially impair the ability to engage in deeper analytic reasoning when solving base-rate conflict problems, in which inhibition of beliefs mediates normative performance. Traditional base-rate problems that offer two conflicting pieces of information are ideal for studying executive inhibitory processes because the reasoner is forced to inhibit one source of information over another to produce a normative response. To illustrate the base-rate problem task once again, reasoners must make a judgment on the likelihood of group membership for an individual (e.g., what is the likelihood that Paul is a doctor?) when offered two pieces of conflicting information: salient base-rates (3 doctors vs. 997 nurses) and a luring, but opposing, stereotypical description (Paul lives in a beautiful home in a posh suburb, is well spoken, interested in politics, and invests a lot of time in his career). Grounded in disinhibition theories associated with ADHD, and taking into account human reasoning practices as outlined by dual process theories, if reasoners are forced to suppress one piece of information when responding either with beliefs or statistics, significant deficits in reasoning performance should be observed with ADHD participants relative to their non-ADHD counterparts when resolving conflict problems using statistics.

The current experiment provided a direct test of this hypothesis. Participants both with and without ADHD solved base-rate problems using Pennycook et al. (2014) instructional manipulation to respond either according to “statistics” (prior probabilities or base-rates) or according to “beliefs” (knowledge of real-world stereotypes). The instruction manipulation differentiates between Type 1 and Type 2 thinking when applied to traditional dual process models and offers an additional advantage of rendering responses to be unambiguously either “correct” or “incorrect” when applied to revised models of dual processes theories of reasoning that suggest multiple streams of Type 1 processes delivering outputs based on either base-rates or beliefs.

Cognitive Reflection Test

The Cognitive Reflection Test (CRT; Frederick, 2005) is a three-item problem-solving task thought to measure individual differences in intuitive- analytic thinking styles (Pennycook, Cheyne, Koehler, Fugelsang, 2015), incorporated into the study as a secondary task to measure the degree of “miserly thinking” by reasoners (Toplak, West, & Stanovich, 2014, p. 147); that is, the unwillingness to expend valuable cognitive resources to engage in deeper analytic reasoning. To answer the CRT correctly, one is assumed to need to inhibit and override an initial and erroneous "gut" response in favour of more analytic one and to engage in further reflection to find a mathematically correct answer (Toplak, West, Stanovich, 2011). This task is evidenced to be a potent predictor of rational thinking performance independent of not only intelligence but also executive functioning and thinking dispositions (Toplak et al., 2014). Take, for example, one of the three CRT questions from Frederic (2005): *A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?* The incorrect answer of 0.10 cents is initially primed. Cognitive misers tend to give the first presented response without further attention to the validity of their answer whereas more analytic thinkers tend to think past the intuitive answer to derive a more suitable response (Toplak et al., 2014). In the case of miserly cognitive processing, the individual holds false confidence for the erroneous response and halts further deliberation. If the ball cost 0.10 cents, the bat would then be 1.10, for a total of 1.20. Inhibiting the first intuitive response and engaging in further reflection might lead to producing the correct mathematical answer of .05 cents. One can see from the bat/ball example that successful inhibition is essential to suppress the intuitively primed response and reflect further on the problem. Given the inhibitory deficits strongly associated with ADHD, the CRT makes an ideal tool for comparing abilities of activating a prefrontal inhibitory mechanism to halt the progress of a prepotent response and allow for further reflection on the problem.

Hypotheses for Study Task 1 – Base-Rate Problems

According to the serial default interventionist account of dual process theories (Evans, 2003), reasoners in both groups should have relatively more difficulty resolving conflict in favour of probabilities than beliefs; however, of interest is the ADHD group, who were expected to have significantly more difficulties relative to their non-ADHD peers in inhibiting a prepotent belief response, as predicted by the disinhibition theories of ADHD (Barkley, 1997b).

1. In the case of the traditional default interventionist (serial) account of dual process theories, in which Type 1 processes form a default response unless there is active and deliberate intervention from Type 2 processes to inhibit and override the Type 1 outputs, the following hypotheses were made:

    a) Individuals with ADHD should have more difficulty inhibiting the autonomously produced belief judgments cued by the stereotypical description when asked to solve conflict problems with statistics. Consequently, belief should cause interference when individuals are asked to provide an answer based on statistics. Difficulty in inhibiting the beliefs would be measured by lower accuracy scores on conflict problems when instructed to answer using statistics.

    b) Consistent with the currents study's three factor design – Group (ADHD or non-ADHD) x Problem Congruency (conflict or non-conflict) x Problem Instruction (Statistics or Beliefs) – a three-way interaction was predicted, such that ADHD reasoners would have more difficulty than their non-ADHD counterparts resolving conflict problems by way of statistics.

2. In the case of more contemporary models of dual process theories, wherein additional Type 1 processes of "logical intuition" are thought to be available for intuitive processing of base-rates or, alternatively, that Type 2 reasoning may not actually be required for base-rate processing, the following hypotheses were made:

a. When solving conflict problems, Type 1 processes will autonomously stream two readily available, yet conflicting responses, (i.e., an intuitive response cued by the stereotypical description and a second Type 1 response intuitively derived from the base-rate information). Individuals should be able to reflect on the two simultaneously streamed Type 1 response options, detect the conflict, and engage Type 2 processes to resolve the conflict between the two Type 1 outputs. However, due to assumed difficulties with inhibitory control, the ADHD group will have more difficulty suppressing the inappropriate response, regardless of which response is to be overruled (one based on belief or one based on statistics). Difficulty in inhibiting the undesirable response option would be measured by lower accuracy scores on all conflict problems, regardless of the response instruction.

b. In this scenario, a 2-way Group x Congruency interaction would be revealed, such that the ADHD group would have more difficulty overall when solving conflict problems relative to non-conflict problems, whereas the control group would demonstrate similar accuracies across levels of congruency. No differentiation would be shown for the different response instructions of "statistics" or "beliefs," as both are assumed to stream from parallel Type 1 processes and both require similar inhibitory capacities, regardless of which response is chosen.

Hypotheses for Study Task 2 – Cognitive Reflection Test (CRT)

1. With respect to the CRT task, it was hypothesized that significant differences would be observed for CRT responses, such that the ADHD group would have more difficulty inhibiting their first intuitive response for purposes of further reflection. Thus, mean accuracies on CRT questions should be considerably lower for the ADHD group relative to the control group.

This concludes the literature review on both ADHD and dual process reasoning, as well an overview of the current study's tasks and hypotheses forecasted for the current study. Chapter Three will provide a detailed outline of the study's research methods and the results of the study. Chapter Four will provide a discussion of the findings and what this means in terms of practical implications for educating students with ADHD, as well as limitations, future directions, and concluding remarks.

CHAPTER 3

METHODS of RESEARCH

This chapter details the research methods of the current study as well as the results of the statistical analyses

Recruitment and Ethics

Participants. Power calculations (Campbell & Thompson, 2012) determined that a sample size of 128 would have 0.8 power to detect a medium (.06) effect. Both male and female adult students of the university were eligible to participate. A general call for participants, both with and without ADHD, was posted on the university's research bulletin website and various hallways throughout the university (see Appendices A and B). An explicit request for participants diagnosed with ADHD was emailed directly to students registered with the University's Disability Services for Students (DSS). Recruitment and testing for the study occurred over the summer and throughout the fall, with both ADHD participants and non-ADHD participants tested concurrently.

In total, 128 individuals from the general university population (66% females) were recruited to participate in the study, each receiving CAN$10 for their participation. Six participants identified themselves as "other" (Control = 2; ADHD = 4), indicating their membership as university alumni (refer to Table 4 for breakdown of College enrollment). As alumni, these individuals had access to university research bulletins soliciting participants. Of the total participants, 64 participants self-reported a formal diagnosis of ADHD and 64 participants self-reported no diagnosis of ADHD (See Tables 3 and 4 for a complete breakdown of demographical information). Ten participants were replaced for answering "yes" to having a learning disability (1 Non-ADHD, 9 ADHD). Three participants were replaced for failing to follow instructions. No participants requested that they be withdrawn from the study.

Participants on medication for ADHD were required to have minimum of 12 hours between the time of the study task and their last dose of ADHD medication. This was accommodated with flexible testing times to minimize disruption to individual medication protocols. Participants not on medication for ADHD symptoms were tested at a time mutually agreed upon by the researcher and participant. The majority of participants compiling the ADHD group were recruited through DSS. When contacting the researcher to ask to be a part of the study, if participants did not volunteer their diagnosis of ADHD, they were asked to confirm: (a) if they had been diagnosed with ADHD; (b) approximately at what age they were diagnosed; (c) by whom (psychiatrist, doctor, or psychologist); and (c) if they are on medication to control symptoms of ADHD. Most participants were either unaware of their particular subtype of ADHD or were oblivious to the fact that there were different subtypes. Complicating the situation was the change in nomenclature in 2000 from ADD to ADHD. Consequently, any participants who had been diagnosed before the year 2000 were diagnosed as having ADD, which did not include a classification according to subtype. Ultimately, it was not possible to accurately classify participants into subtypes of ADHD.

Ethics. Ethics approval from the University of Saskatchewan's Behavioural Ethics Research Board was obtained before commencing testing (BEH 15-147). All participants had the opportunity to provide informed consent before participating in the study (see Appendix C). Following the task, participants were supplied with a debriefing information sheet and given an opportunity to ask questions (see Appendix D).

Materials and Procedures

Two study tasks were designed for the experiment. As a measure of reasoning performance, the first task required participants to solve 24 base-rate problems in free time by way of either "beliefs" or "statistics." A second problem task asked participants to solve three simple logic questions from the CRT (Frederic, 2005). Results of the CRT were matched against both the group variable and the reasoning performance. A further discussion of the CRT and anticipated correlations will follow later in this section. Altogether, the study task took the expected 30 minutes or less.

Permission was granted from Gordon Pennycook to use the base-rate neglect problems from Pennycook et al.'s (2014) study, as adapted from De Neys and Glumicic's (2008) study. Instructions for the base-rate problems were adapted from Pennycook et al. (2014). Participants carried out the computerized tasks either individually or in groups of up to three people using individual Microsoft computers in the Social Sciences Research Laboratory at the university. As part of the study, participants were prompted to provide demographical information of age, sex, year of study, college of study, and total years to date of university education. Following Study Task #1, participants were also prompted to answer the following questions:

1. Have you been diagnosed with ADHD? (yes or no)

If the answer was “no,” participants were automatically redirected to question four.

2. Are you on medication for ADHD? (yes or no)

3. How many hours since your last dose of medication for ADHD? ___ hours

4. Have you been diagnosed with a learning disability? (yes or no)

5. Have you been diagnosed with test anxiety? (yes or no)

6. Are there any other factors that might have impeded your performance in this study?

The above questions were used as a screening tool to obviate confounds from learning disabilities such as dyslexia or dyscalculia that may have influenced participants’ test performance. Those participants who answered “yes” to having being diagnosed with a learning disability were replaced. In total, 9 participants in the ADHD group and 1 participant in the non-ADHD group were replaced for having been diagnosed with a learning disability.

In designing the study, consideration was given to the influence of test anxiety and/or generalized anxiety on participants’ responses. It was originally thought that participants who indicated a diagnosis of test anxiety or a history of anxiety would be replaced. The incidence of comorbid anxiety with ADHD is quite high, as reflected in the number of “yes” responses to question five of the screening questions (test anxiety) and abundant written responses of generalized anxiety for question six, most of which, save one, was noted by ADHD participants. The rate of comorbid anxiety in ADHD participants for this study was 16%, slightly lower than documented average rates for comorbid anxiety (Adler et al., 2007; Brown, 2000; Jensen et al., 2001; Mayes et al., 2009; Merikangas et al., 2009). It became difficult to find willing participants to volunteer who had a diagnosis of ADHD and had no a history of test anxiety or generalized anxiety. As such, a decision was made to keep data from participants who answered “yes” to test anxiety as well as from those who acknowledged a condition of generalized anxiety.

Medications. Most medications used to treat ADHD have their effects dissipated within 12 hours of the initial dose (Johnson & Parker, 2004; see also Table 5 for breakdown). To protect against effects of ADHD medication, participants taking medication for ADHD were requested to have a minimum of 12 hours between their last medication dose and the time of the study task. Participants with ADHD who confirmed use of psychotropic medication(s) to treat ADHD were instructed to delay taking stimulant medication(s) at least 12 hours before testing if they took medication twice a day and 24 hours before testing if they took medication once a day. A computerized check during the actual study asked participants to: a) indicate if they had been diagnosed with ADHD; b) indicate if they were on medication for ADHD; and c) indicate how many hours it had been since their last dose of such medication. Of the 64 participants with ADHD, 27 (42%) were prescribed stimulant medication. Of these, one participant had taken medication 15 hours prior to testing, one at 17 hours prior to testing, two had taken medication 20 hours prior to testing, and the remaining 23 participants had taken medication at least 24 hours or more prior to testing.

Study Task 1. Each participant solved a total of 24 base-rate problems in free time by providing a probability estimate out of one hundred on the likelihood of group membership (see Appendix E). Using Pennycook et al.'s (2014) instructional manipulation, participants respond either according to 'statistics' (prior probabilities or base-rates) or according to 'beliefs' (knowledge of real-world stereotypes). The goal of the instruction manipulation was two-fold: (a) it avoided confusion as to what constituted a "correct" answer; and (b) it made a distinction between faster Type 1 processes correlated with intuitive answers and the slower Type 2 processes correlated with logical/probabilistic thinking. If utilizing base-rates requires Type 2 processing, they should not interfere with the processing of the presumably faster belief-based judgments, whereas belief-based judgments should always interfere with statistics judgments. Problem Type was defined by the congruency between the descriptive information and presented base-rates. Conflict problems were those in which the base-rates and description elicited opposing responses; non-conflict problems were those in which the base-rates and description elicited the same response. An example of each is shown here:

> Conflict (Incongruent) Problem: *In a study 1000 people were tested. Among the participants were 996 nurses and 4 doctors. Paul is a randomly chosen participant of this study. Paul is 34 years old, lives in a beautiful home in a posh suburb, is well-spoken, interested in politics, and invests a lot of time in his career. What is the probability that Paul is a doctor?*
>
> Non-conflict (Congruent) Problem: *In a study 1000 people were tested. Richard is a randomly chosen participant of this study. Richard is 56 years old. He is a good public speaker and is good at meeting people. He is a top notch debater and can argue both sides of an issue with ease. Among the participants there were 5 I.T. Technicians and 995 politicians. What is the probability that Richard is a politician?*

Conflict and non-conflict problems were created by interchanging the ratio of small and large base-rates, so that a congruent problem can be made incongruent simply by switching the base-rate figures. The following is an example of base-rate alteration to offer both conflict and non-conflict problems with similar content:

Conflict (Incongruent) Problem: *In a study 1000 people were tested. Among the participants there were 5 engineers and 995 lawyers. Jack is a randomly chosen participant of this study. Jack is 36 years old. He is not married and is somewhat introverted. He likes to spend his free time reading science fiction and writing computer programs. What is the probability that Jack is a lawyer?*

Non-conflict (Congruent) Problem: *In a study 1000 people were tested. Among the participants there were 995 engineers and 5 lawyers. Jack is a randomly chosen participant of this study. Jack is 36 years old. He is not married and is somewhat introverted. He likes to spend his free time reading science fiction and writing computer programs. What is the probability that Jack is a lawyer?*

For consistency with previous base-rate reasoning studies, extreme base-rate ratios were used (e.g., De Neys & Glumicic, 2008; De Neys et al., 2008; Pennycook et al., 2014; Pennycook & Thompson, 2012; Thompson et al., 2011). Three ratios of base-rates were presented an equal number of times in problems (995/5; 996/4; 997/3). The groups that were asked about in the final question (e.g., What is the probability that …?) were counterbalanced in such a way that the question would pertain to the larger group (e.g., 995) half the time and would pertain to the smaller group (e.g., 5) half the time. Problem Type was manipulated within participants, such that half of the problems were conflict and half were non-conflict. Each participant was presented with 12 conflict problems and 12 non-conflict problems, with problems counterbalanced so that each problem type appeared equally often in each form across all participants and problem content was not repeated within each participant's set. Problem order was randomized by computer assignment for each participant. For counterbalancing examples, see Appendix F.

Problems were displayed individually on the computer screen and remained visible to participants while they were deliberating on their response. Participants were given free time to determine their answer. The following exemplifies the instructions displayed on the computer screen at the beginning of each trial:

For each problem, you will be cued to answer either according to beliefs or according to statistics. When instructed to answer according to your beliefs, this means you must answer according to your knowledge of what you think to be true in the world. For example, if you met someone on the street who is dressed in very ragged clothing and asking for money, it is a good bet that such a person is homeless. If you were to be asked the probability that such a person is homeless, you would want to give a high probability because, based upon our knowledge of the world, people who dress in ragged clothing and ask for money on the street are usually homeless.

By contrast, when instructed to answer according to statistics, this means you must assume that your prior beliefs about the world aren't necessarily relevant. Instead, you should concentrate on the actual probability that something will happen. For example, if you knew that only a small percentage of people in a city were homeless, then you would want to give a low probability because, based on statistics, only a small percentage of people are homeless.

The instruction manipulation was counterbalanced across participants, such that the problems presented with instructions to respond to "belief" to half the participants were presented with instructions to respond according to "statistics" for the other half, and vice versa. Participants were prompted with "BELIEF" or "STATISTICS" at the bottom of the screen for each problem in a randomized order. After solving each problem, participants were asked to rate the confidence of their answer on a scale of 1 – 9, with "1" reflecting low confidence and "9" reflecting high confidence. As part of the data collection, participants were asked to enter into the computer their strategy for responding using "beliefs" as well as their strategy for responding with "statistics."

Study Task 2. Upon completion of the base-rate task, participants solved three logic questions in free time as obtained from the CRT (see Appendix G). The CRT is a three-item problem-solving task designed to measure the tendency to override an initial erroneous "gut" response and to engage in further reflection to find a more suitable answer. The CRT task is evidenced to be a potent predictor of rational thinking performance independent of not only intelligence but also executive functioning and thinking dispositions (Toplak et al., 2014). Accuracy on the CRT is positively correlated with abilities on decision-making tasks (Frederick, 2005; Toplak et al., 2011, 2014); analytic reasoning tasks (De Neys, 2013; Toplak et al., 2011, 2014), and has been found to be negatively correlated with religious beliefs (Pennycook, Cheyne, Seli, Koehler, & Fugelsang, 2012). Responses for the CRT identify reasoners who tend to be stingy with cognitive resources – that is, the unwillingness to engage Type 2 processes and working memory to engage in further reasoning, which is also a marker for thinking disposition (Toplak et al., 2014). For example, cognitive misers tend to give the first response that comes to mind without further attention to the validity of their answer (Toplak et al., 2014) whereas more analytic thinkers tend to think past the intuitive answer to derive a more suitable response.

RESULTS

The experiment consisted of a 2 x 2 x 2 [participant (ADHD, non-ADHD) x description (conflict, non-conflict) x instruction (answer using beliefs, answer using statistics)] mixed-factorial design. The factor of "participants" was classified as a "between-subject" factor; factors of "description" and "instruction" were classified as "within-subject factors." The following dependent variables were examined: probability estimates recorded as a mean ratio of participants' accuracies; mean confidence judgments, recorded using a scale of 1 – 9; response times (RTs), measured in milliseconds; CRT response accuracies, measured as a mean ratio of the number correct; and CRT RTs, measured in milliseconds.

Missing Values

No missing values were recorded.

Data Cleaning and Rescoring

Prior to evaluating the hypotheses of the current research, data were screened for issues concerning the normality of the distribution (e.g., outliers, skewness, and kurtosis) that may have affected the analysis and/or interpretation of the results. An initial exploratory analysis using SPSS statistical software was carried out to identify data points judged to be outliers for dependent variables of probability estimates, RTs, confidence ratings and CRT RTs were deleted from the data set before analyses. CRT responses were coded either as 1 for mathematically correct or 0 for incorrect.

To facilitate data analyses, responses from base-rate problems were rescored so that high scores always reflected answers that were consistent with the correct response as per the response instruction. More explicitly, when the correct answer according to instructions specified a low probability, response estimates were subtracted from 100. To illustrate rescoring, the example of the lawyer/engineer conflict problem is given:

In a study 1000 people were tested. Among the participants there were 5 engineers and 995 lawyers. Jack is a randomly chosen participant of this study. Jack is 36 years old. He is not married and is somewhat introverted. He likes to spend his free time reading science fiction and writing computer programs. What is the probability Jack is a lawyer?

When responding under the statistics instruction, the correct answer that Jack is a *lawyer* would indicate a high probability. In this case, no rescoring of the data is necessary. However, if the question was changed to "what is the probability that Jack is an *engineer*," the correct response according to "statistics" would be 0%. In this case, all responses, regardless of the number, were rescored (100 – response) to ensure that high scores reflected correct answers. Using this same example, but under a "belief" instruction, the correct answer for "what is the probability Jack is an *engineer*" would suggest a high probability estimate and no rescoring was required, regardless of participants' estimates. However, when asked about the probability of being a *lawyer* under the "belief" instruction, the correct answer should be "0." In this case, all responses were rescored (100 – response), to ensure that high scores reflected correct answers.

Individual repeated-measures ANOVAs were used to analyze the 128 participant responses for probability estimates, confidence ratings, and RTs. Post hoc paired *t*-tests were used to interpret any interactions, together with Bonferroni corrections to control for inflation of Type 1 error. Means and standard deviations for estimates, confidence ratings, and RTs are reported in the Tables section. Graphed means for interactions are shown in the Figures section.

Responses for the three CRT questions were recoded, such that mathematically correct answers were coded as 1 and incorrect answers were coded as 0. Mean CRT responses for each participant were converted to a percent to reflect 0 for none correct, 33 for one correct, 67 for two correct, and 100 for three correct. Means of CRT responses were analyzed using a *t*-test to determine differences in performance differences between groups, as measured by accuracy. Additionally, a bivariate correlation was carried out to determine associations between CRT responses, responses under the belief instruction, and responses under the statistic instruction.

Analysis of Probability Estimates

The means for the 2 x 2 x 2 analysis of probability estimates are shown in Tables 6-9. Graphed results and histograms of probability estimates are illustrated in Figures 3-8. Means for probability estimates are reported as a ratio of accuracy, with 100 representing a correct answer in all conditions. Interactions were parsed with *t*-tests using a Bonferroni correction ($\alpha = .025$).

The manipulation of problem congruency allowed interference to be measured between the two processing systems (Type 1 and Type 2) when problem-solving. As expected, a main effect of congruency was observed, $F(1,121) = 202.27$, $MSE = 255.20$, $p < .001$, $\eta_p^2 = .626$), which revealed the anticipated higher accuracies for non-conflict problems ($M = 86.63$, $SD = 10.14$) relative to conflict problems ($M = 65.88$, $SD = 15.16$). A main effect of group, $F(1,121) = 9.62$, $MSE = 383.56$, $p = .002$, $\eta_p^2 = .074$), and instruction, $F(1,121) = 19.88$, $MSE = 475.83$, $p < .001$, $\eta_p^2 = .141$), was qualified by a Group x Instruction interaction, ($F(1,121) = 4.34$, $MSE = 475.83$, $p = .039$, $\eta_p^2 = .035$). The interaction was deconstructed using a paired *t*- test to measure differences in observed means between groups for the two response instructions. For the control group, a mean difference of 4.67% between the two response instructions was found to be non-significant ($t(60) = 1.62$, SE = 2.88, $p = .110$). That is, the control group had similar accuracies whether responding with beliefs or statistics. For ADHD participants, a mean difference of 12.87% between the two response instructions was found to be significant ($t(61) = 4.80$, SE = 2.68, $p < .001$). These differences remained significant after a Bonferroni correction ($\alpha = .0125$). Specifically, the ADHD group performed significantly better for the statistic instruction relative to the belief instruction ($M = 84.97$ $SD = 16.43$) and ($M = 72.49$, $SD = 13.03$), respectively, whereas for the control group, estimates for statistics and beliefs were relatively similar, $M = 76.02$ ($SD = 16.44$) and $M = 71.40$ ($SD = 12.48$), respectively. Consequently, while both ADHD participants and controls were observed to have similar accuracies when solving problems with beliefs, the ADHD participants revealed significantly higher accuracies when solving problems with statistics, suggesting their problem-solving technique for the conflict/statistic condition was somewhat different than controls.

Marginally significant differences in means were observed for the 3-way interaction, $F(1,121) = 3.54$, $MSE = 536.04$, $p = .062$, $\eta_p^2 = .028$), which revealed the ADHD group to have equal or better accuracy performance relative to controls. Despite principles of sequential processing outlined in the default interventionist model of reasoning and the inference of one-way interference (beliefs interfere with base-rates, not vice versa), graphed results of probability estimates (Figure 3) clearly illustrate two-way interference on conflict problems. Specifically, control participants had similar accuracy when resolving conflict with beliefs ($M = 60.78$, $SD = 23.25$) as when resolving conflict with statistics ($M = 64.68$, $SD = 28.92$). The comparable accuracies suggest that base-rates interfered with beliefs to the same extent that beliefs interfered with base-rates, an observance that substantiates the accessibility of base-rates to Type 1 processes. This finding supports a parallel processing model, in which dual streaming Type 1 processes deliver multiple outputs derived from base-rates and beliefs, both of which must then be compared and contrasted to make a final judgment.

Similarly, the ADHD group's accuracy when resolving conflict with beliefs (M = 59.13, SD = 25.83) was also comparable to the control group's accuracy when resolving conflict with beliefs (M = 60.78, SD = 23.25), indicating similar levels of interference from base-rates in the conflict/belief condition. However, what is striking is that the ADHD group had considerably less interference from *beliefs* when resolving conflict with *statistics*, as illustrated by the ADHD group's higher accuracy rates in the conflict/statistic condition (M = 78.93, SD = 24.34) relative to controls (M = 64.68, SD = 28.92). Thus, while the control group's interference from beliefs when solving with conflict problems with statistics was similar to what has been observed in similar studies (Pennycook et al., 2012, 2014; Pennycook & Thompson, 2012, but see De Neys, 2012 for a review), clearly something was happening with the ADHD group to produce such high accuracy rates in the conflict/statistics condition.

Analysis of Response Times for Probability Estimates

The means for the 2 x 2 x 2 analysis of response times (RTs) are shown in Tables 10-13 and graphed in Figures 9 and 10. Means for RTs are reported in milliseconds. Interactions were interpreted with t-tests using a Bonferroni correction ($\alpha = .0125$). A main effect of congruency, $F(1,114) = 22.48$, $MSE = 21033843.88$. $p < .001$, $\eta_p^2 = .165$), and instruction, $F(1,114) = 16.83$, $MSE = 45600276.08$, $p < .001$, $\eta_p^2 = .129$), and a non-significant effect of group, $F(1,114) = 3.60$, $MSE = 150481901.31$, $p = .060$, $\eta_p^2 = .031$, formed a Group x Instruction x Congruency interaction, $F(1,114) = 7.20$, $MSE = 15747438.89$, $p = .008$, $\eta_p^2 = .059$). The marginally significant main effect of group (p = .060) is manifested as a cross-over effect for the non-conflict/statistic condition in the deconstruction of the three-way interaction, illustrated in Figure 10. Evidence that base-rates interfered with belief judgments to the same extent that stereotypes interfered with statistical judgments was demonstrated by congruency effects of increased RT for conflict problems relative to non-conflict. The three-way interaction reveals the joint effects of all three factors on RT. That is, RT depended on the interaction of group membership, instruction, and congruency. To parse out the 3-way interaction, a two-way ANOVA of Group x Instruction was initially run using only conflict problems. This revealed main effects for instruction for conflict problems ($F(1,119) = 12.77$, $MSE = 36165780.20$, $p = .001$ $\eta_p^2 = .097$), such that overall latencies under the belief instruction for conflict problems ($M = 20734.97$, $SD = 10176.31$) were longer than latencies under the statistic instruction (M = 17123.49, SD = 6567.54). A main effect of group was also observed for conflict problems ($F(1,119) = 4.17$, $MSE = 945751.82.77$, $p = .043$ $\eta_p^2 = .034$), such that the ADHD group took longer to solve conflict problems ($M = 18278.52$, $SD = 5838.48$) relative to the control group ($M = 16117.54$, $SD = 6405.56$). No interaction effects were observed for factors of group and instruction in conflict problems ($F(1,119) = .001$, $MSE = 361657.80.20$, $p = .979$, $\eta_p^2 < .001$). A second ANOVA of Group x Instruction was then run for non-conflict-problems. This revealed a main effect of Instruction ($F(1,118) = 15.37$, $MSE = 25296674.98$, $p < .001$ $\eta_p^2 = .115$), but no main effects of group ($F(1,118) = 2.35$, $MSE = 80710040.22$, $p = .128$ $\eta_p^2 = .020$). Together this formed an Instruction x Group interaction, ($F(1,118) = 9.32$, $MSE = 25296674.98$, $p = .003$ $\eta_p^2 = .073$). Paired t-tests revealed that the control group's RTs for non-conflict problems were similar when solving with beliefs ($M = 16016.84$, $SD = 7488.01$) and statistics ($M = 15331.02$, $SD = 7162.60$), ($t(61) = .715$, $SE = 788.99$, $p = .478$). However, the ADHD group had significantly longer RTs when resolving non-conflict problems with beliefs ($M = 20400.91$, $SD = 9116.25$) relative to solving non-conflict problems with statistics ($M = 15360.94$, $SD = 5174.62$), ($t(57) = 4.33$, $SE = 1045.79$, p <.001). This finding remained significant with a Bonferroni correction ($\alpha = .0125$).

The observed pattern of response latencies is quite intriguing, as it exposes undeniable difficulties experienced by the ADHD group that went undetected in the analyses of probability estimates. Plotted results in Figure 9 provide a closer look at RT differences among various conditions. Symmetrical RTs for the ADHD group in both conflict and non-conflict belief conditions ($M = 22014$ and $M = 20401$, respectively) strongly suggest that, despite equivalent accuracies relative to the control group for problems solved with beliefs, the ADHD group struggled to extract the meaning of the protracted personality descriptions. Compelling evidence of the ADHD group's difficulty to encode descriptions lies in the observation that problem congruency did not appear to influence RTs; that is, ADHD participants took just as long to solve conflict problems with beliefs as they did non-conflict, suggesting a high level of difficulty interpreting and encoding the lengthy and ambiguous descriptions. By comparison, the control group's significantly longer RTs for conflict/belief problems ($M = 19456$) relative to non-conflict/belief problems ($M = 16017$) signify the congruency effects one would expect.

Interestingly, the pattern of response latencies for problems solved with *statistics* also exposed performance difficulties for the ADHD group. Although probability estimates for the ADHD group were much higher than controls in conflict/statistic condition (*M* = 79 vs. *M* = 65, respectively), RTs between the two groups reveal the ADHD group to require significantly longer latencies than controls (*M* = 18400 vs. *M* = 15826, respectively) to solve problems in the conflict/statistic condition. Moreover, a comparison of differences between groups in both the conflict/statistic and non-conflict/statistic conditions is illuminating. The control group exhibits symmetrical RTs between the *conflict*/statistic condition (*M* = 15826) and *non*-conflict/statistic condition (*M* = 15331), suggesting that for the control group, solving conflict problems with statistics was no more difficult than solving *non*-conflict problems with statistics. Conversely, the ADHD group's significantly longer RTs when solving problems in the *conflict*/statistic condition (*M* = 18400) as compared to the *non*-conflict/statistic condition (*M* = 15361) clearly indicates that, despite higher accuracies, the ADHD had far more difficulty solving problems in the *conflict*/statistic condition. Longer RTs in the conflict/statistic condition by ADHD participants are at odds with their substantially higher accuracy rates for the same condition. Given the ADHD group's evidenced struggles to process the wordy descriptions when asked to solve problems with beliefs (discussed above), one would assume that difficulties encoding descriptions would result in less interference from beliefs when resolving conflict with statistics, thus eliciting higher accuracies under the statistics instruction. However, the need for longer latencies when solving conflict problems with statistics certainly implies difficulties and refutes assumptions of minimal interference from beliefs. From the pattern of RTs, it is clear the ADHD group was having more difficulties solving conflict/statistic problems than controls, which can only be attributed to difficulties with inhibiting interference. Thus, while the ADHD group may have had difficulty encoding the descriptions, they must have encoded them well enough to create significant interference when resolving conflict with statistics. Hence, longer RTs for the ADHD group in the conflict/statistic condition are likely due to the additional time required by ADHD reasoners to overcome inhibitory deficits and suppress interference from beliefs.

Altogether, the analysis for response latencies has revealed a clearer picture of what is happening during problem-solving for the ADHD group and reflect two areas of difficulty that ADHD participants struggled with. First, the symmetrical pattern of longer RTs in both the conflict/belief and *non*-conflict/belief conditions clearly indicates that the ADHD group had considerable trouble encoding wordy personality sketches. A second finding is that, despite the ADHD group's difficulty encoding the lengthy descriptions, they did encode them sufficiently to produce interference when solving conflict problems with statistics. The longer RTs observed for ADHD reasoners when resolving conflict problems with statistics likely expose the predicted inhibitory deficits associated with ADHD and how ADHD reasoners overcome these deficits.

Analysis of Confidence Ratings

The means for the 2 x 2 x 2 analysis of confidence ratings are shown in Tables 14-17. Mean confidence ratings were documented using a scale of 1-9, with "1" reflecting low confidence and "9" reflecting high confidence. As expected, congruency effects were echoed in confidence ratings ($F(1,123) = 61.15$, $MSE = .356$, $p < .001$, $\eta_p^2 = .332$), with participants having more confidence in their responses for non-conflict problems ($M = 7.62$, $SD = .89$) than conflict problems ($M = 7.20$, $SD = 1.00$), further evidencing effects of two-way interference of base-rates and stereotypes. Consistent with accuracy rates for estimates, a main effect of instruction ($F(1,123) = 9.00$, $MSE = 1.40$, $p = .003$, $\eta_p^2 = .068$) showed confidence ratings to be higher when responding with statistics ($M = 7.55$, $SD = 1.10$), than when responding with beliefs ($M = 7.29$, $SD = .960$), an observation that supports the implementation of a cost-effective strategy by both groups of reasoners. Mean confidence ratings between groups were not significantly different, $F(1,123) = 1.49$, $MSE = 3.23$, $p = .225$, $\eta_p^2 = .012$), with similar confidence ratings for the control group ($M = 7.51$, $SD = .82$) relative to the ADHD group ($M = 7.31$, $SD = .97$). No significant interactions between factors for confidence ratings were observed. What is curious is that even though the longer RTs in specific conditions for the ADHD group suggest more difficulty solving these problems, no interactive effects were observed in confidence ratings. This implies that, while the ADHD group had difficulties with both encoding beliefs and inhibiting interference, the extended RTs provided them with the additional means to attain accuracy rates similar to that of controls, thus eliciting comparable confidence ratings.

Analysis of Cognitive Reflection Test (CRT)

Group means for CRT responses, RTs, and correlations are listed in Tables 18-21. In contrast to expectations, no significant group differences reported on the CRT task, $t(126) = 1.82$, $SE = 6.31$, $p = .071$, with a mean percent correct for the ADHD group (46.34) observed to be only slightly higher than that for the control group (34.86). CRT measures were consistent in that accuracy under the statistics instruction was correlated with accuracy of CRT responses (N =

125, $r = 0.374$, $p < .001$, $\alpha = .01$). The correlation is not surprising, as reasoners who are able to engage Type 2 processes and successfully inhibit the initially intuitive belief response on CRT problems should also have proficiency with problem-solving when responding with statistics. Alternatively, the correlation may be due to numerical competency, as both problem types involve a facility with numbers. A similar pattern of correlation between CRT responses and the belief instruction was not revealed (N = 126, r =.023, $p = .797$, $\alpha = .05$). In other words, CRT responses, which are correlated with thinking style (i.e., whether one has tendencies of miserly information processing or a deeper analytic style of thinking) were not associated with one's capacity to solve problems intuitively using beliefs based on experiential knowledge. The equivalent CRT scores between groups are, at face value, counterintuitive to expectations, as inhibitory deficits should have constituted poorer performance for the ADHD group.

Consistent with group differences in RTs on the base-rate task, significant differences were observed between groups for latencies in the CRT task, $t(120) = 2.25$, $SE = 4257.60$, $p = .026$), with the ADHD group taking longer to resolve CRT problems ($M = 46210.33$, $SD = 24920.33$) than the control group ($M = 36626.88$, $SD = 22016.67$). The longer RTs for the CRT task by the ADHD group align with the longer latencies observed for the ADHD group when resolving conflict in base-rate problems and support assumptions that inhibitory deficits may be manifested in response latencies. Thus, longer RTs for the ADHD group in the CRT task may be due to the additional time required to successfully suppress the inappropriate response.

This concludes the overview of results for the current study. Chapter Four will provide a discussion of the findings, including practical implications for education, limitations of the study, future directions for further study, and concluding remarks.

CHAPTER 4
DISCUSSION

It was very surprising to observe that accuracy rates for participants with ADHD were not lower relative to their non-ADHD counterparts when asked to solve base-rate problems with statistics. Moreover, results from the CRT task revealed the ADHD group to be on par in accuracy relative to the control group in solving CRT problems. Considering ADHD is predominantly linked to difficulties in inhibition, attention to tasks, and using working memory effectively (Barkley, 1997b, Brown, 2008, Clark et al., 2007), this was entirely unexpected.

Discussion of Cognitive Reflection Test (CRT)

The CRT was based on the original work of Frederick (2005) and further studied, among others, by Toplak et al. (2011, 2014). The logic of the CRT requires the assumption that intuitive responses cued by the problems are common to most reasoners, but that the tendency and ability to inhibit and override these prominent intuitions depends on individual differences in thinking styles (Pennycook, Cheyne et al., 2015). The CRT has been touted as the hallmark for evaluating the ability to "reflect upon and ultimately override the intuitive responses" (Pennycook, Cheyne et al., 2015, p. 2). Accuracy rates observed by the ADHD group on this task did not reveal the widely acknowledged inhibitory deficits. Specifically, both groups correctly answered about one out of the three CRT questions, a figure that correlates with performance for web-based and college samples (Pennycook, Cheyne et al., 2015), and one that was slightly lower than had by students from Ivy League colleges, such as Princeton and the Massachusetts Institute of Technology (Frederick, 2005). Given the inhibitory deficits associated with ADHD, one wonders how they managed to match the control group's accuracy levels. Perhaps the answer can be found in the significantly longer latencies observed for the ADHD group. It is possible that the longer RTs are manifestations of their inhibitory control deficiencies[3]. Thus, to fully engage the executive inhibitory mechanism and successfully supress the intuitive response, the ADHD group require longer latencies relative to the control group. While inhibitory impairments likely made the process of inhibiting the intuitive, through erroneous, answer more difficult, the additional RT facilitated performance levels that matched controls. Unlike the base-rate task, the CRT task does not support strategy use. One must inhibit

[3] V. Thompson, personal communication, May 4, 2016

the intuitive response and perform a mathematical operation to compute the correct answer. Although math competency could be related to problem-solving proficiency, given the inhibitory deficits linked to ADHD, it is more likely that longer RTs for the ADHD group needed to solve CRT problems are attributable to overcoming inhibitory deficits rather than to math difficulties.

Discussion of Base-Rate Task

Conflict Detection. Similar probability estimates for the *control* group when solving conflict problems under both the belief and statistic instructions clearly reveal that base-rates interfered with beliefs to the same extent that beliefs interfered with base-rates, also known as two-way interference. This contradicts explicit operational tenets outlined for serial models of dual process theories that stipulate one-way interference (beliefs should only interfere with base-rates, not vice versa). Also evidenced were strikingly similar reduced accuracy rates for both groups when solving conflict problems under the belief instruction, indicating interference from base-rates. The symmetrical estimates for both groups demonstrate that both groups were, at least implicitly, aware of conflict from base-rates when solving problems with beliefs and these base-rates interfered to the same extent for both groups. The observation of two-way interference verifying the accessibility of base-rates to Type 1 processes matches that of previous reasoning studies that also used extended base-rates as stimuli for base-rate problem solving (see De Neys, 2012 for a review, but also see Pennycook et al., 2012, 2014; Pennycook & Thompson, 2012; Thompson et al., in press; Thompson & Johnson, 2014). Further evidence of early conflict detection was also revealed through increased RTs for both groups on conflict problems relative to non-conflict problems and by decreased confidence ratings by both groups on conflict problems as compared to non-conflict. Altogether, these findings offer additional support for claims that easily distinguishable base-rates (e.g., 997/3) are accessible to Type 1 processes, reinforcing the idea that humans have a probabilistic intuition for processing extreme base-rates (De Neys, 2012; Pennycook et al., 2012, 2014, Pennycook & Thompson, 2012; Thompson et al., in press; Thompson & Johnson, 2014), regardless if reasoners have responded with beliefs or probability. Thus, it is possible for reasoners to have several Type 1 processes streaming parallel judgements – one derived from base-rates and one derived from beliefs.

The question remains as to how reasoners resolve conflict between two Type 1 outputs founded on contradictory sources of information. Not surprisingly, a congruency effect was evidenced in the analysis of RTs, such that conflict problems required more time to resolve than non-conflict problems, an observation that supports conflict detection in reasoning. What is more interesting, though, is a main effect of group for response latencies in conflict problems, such that ADHD reasoners took much longer to solve conflict problems than controls. If, in fact, longer latencies are a manifestation of inhibitory deficits, then by extension, a case could be made to support assumptions that engagement of Type 2 processes (and thus inhibitory control) is necessary to resolve the conflict between two parallel streaming Type 1 outputs (De Neys, 2012; Pennycook et al., 2012, 2014), one derived from beliefs and the other from base-rates.

Solving with Statistics. A wealth of solid evidence, including that of executive function tests (e.g., go/no-go task, Stroop task, Stop task, Continuous Performance Test), neuroimaging studies, and neuro-physiological studies overwhelmingly support disinhibition theories as a primary dysfunction in ADHD (Barkley, 1997b, but see Nigg & Barkley, 2014). Despite this evidence, accuracy rates on a base-rate task widely thought to demand inhibitory control did not reveal the expected poorer reasoning abilities for the ADHD group.

Significantly higher accuracy rates observed by the ADHD group in the conflict/statistic condition (Figures 3 and 4) suggest that when asked to resolve conflict problems using statistics, ADHD reasoners recognized the conflict and did a better job of resolving this conflict relative to controls. In spite of their superior performance, confidence ratings for the ADHD group were revealed to be similar to that of controls. This raises the question of *how* ADHD thinkers reasoned through the problems requiring a statistical response. Overall RTs for both groups under the statistics instruction were observed to be notably lower than when solving problems under the belief instruction. This implies that when problem-solving with statistics, both groups likely implemented a cost-effective strategy to rapidly extract the clear, salient, numerical base-rate information– a strategy that could not be applied when problem-solving with beliefs. However, from the observed higher accuracy rates of the ADHD group, it appears that ADHD reasoners were both more uniform and persistent in applying this numerical strategy than their non-ADHD counterparts. Notwithstanding their resolute strategy use that likely resulted in higher accuracies, the pattern of RTs revealed the ADHD group to require more time to solve problems in the conflict/statistic condition relative to controls, suggesting they experienced more difficulty with these problems than controls.

Response latencies for *controls* when resolving conflict problems with statistics reveals similar behavioral patterns as that found in other base-rate studies (Pennycook et al., 2012, 2014;

Pennycook & Thompson, 2012; Thompson & Johnson, 2014). Specifically, when resolving conflict problems with statistics, controls appear to trade-off accuracy in favor of speed, thus demonstrating symmetrical response latencies between conflict problems solved with statistics and *non*-conflict problems solved with statistics. However, this rapid response time in the conflict/statistic condition costs them in accuracy, ostensibly due to interference from beliefs.

Alternatively, the ADHD group was observed to do the reverse, in that they relinquished speed in favor of accuracy when resolving conflict with statistics. Thus, unlike controls, ADHD reasoners were observed to have significantly longer latencies for the conflict/statistic condition relative to the *non*-conflict/ statistic condition, but this trade-off benefited them in terms of accuracy, as shown by considerably higher accuracy rates when resolving conflict with statistics.

The parsimonious explanation for the different approaches between groups is likely due to conflict effects and the speed and proficiency with which the respective groups can inhibit interference. The control group was not assumed to have inhibitory deficits; hence, they could presumably solve conflict problems with greater speed but compromised some accuracy in the process (i.e., accuracy traded for speed). The ADHD group, however, are known to have inhibitory deficits that likely hampered their speed and proficiency for problem-solving in the conflict/statistic condition. Thus, just as with the CRT task, the observed longer response latencies for ADHD participants in the conflict/statistic condition may be an index of the inhibitory deficits associated with ADHD and the time it takes to overcome these deficits.[4] Accordingly, when resolving problems with statistics, ADHD reasoners required longer latencies to inhibit interference from beliefs, but if given the time to do so, they were more consistent at inhibiting interference (i.e., speed traded for accuracy). Thus, it is not that ADHD reasoners *cannot* successfully engage inhibitory control; it is that it takes them *longer* to engage this control but can eventually respond with the same confidence as their non-ADHD peers. Moreover, when provided this extended time to resolve conflict with statistics, they appear to demonstrate more consistency and persistence in applying this inhibitory control than controls.

Solving with Beliefs. The observation that ADHD reasoners required similar latencies to solve problems under the belief instruction (Figures 9 and 10) exposes additional difficulties for ADHD reasoners. Symmetrical latencies for ADHD reasoners when problem-solving with

[4] V.Thompson, personal communication, May 4, 2016

beliefs, regardless of the congruency of the problems (conflict or non-conflict), suggest that the ADHD group had great difficulty encoding the prolix descriptions. Thus, although ADHD reasoners' accuracy rates for solving with beliefs was equal to controls, it took them significantly longer to achieve this parallel performance, even when solving problems that did not contain conflict. This finding supports the vast literature citing working memory and processing speed inefficiencies in the ADHD brain (Au et al., 2014; Holmes et al., 2010; Lewandowski, Lovett, Parolin, Gordon, & Codding, 2007; Martinussen et al., 2005; Willcutt et al., 2012) and provides an explanation as to why students with ADHD often require extended time to complete school course work and exams. Interestingly, observed confidence ratings revealed no differences in certainty of responses between groups when solving all problems with beliefs. Once again, this suggests that, despite the difficulties experienced by ADHD reasoners, given enough time they can respond with the same confidence as their non-ADHD counterparts. Altogether, this justifies common policies by school administrators to provide extra time to students with ADHD as a means to facilitate their academic success and progression to higher academic levels.

High Capacity Reasoners

Interestingly, the pattern of thinking observed in the ADHD group is similar to that found in high-capacity (IQ) reasoners (Thompson & Johnson, 2014; Thompson et al., in press), although likely for different reasons. Thompson and Johnson (2014) and Thompson et al. (in press) observed that differences in reasoning based on cognitive style may emerge at an early stage in processing (Peters, 2012; Peters, Slovic, Västfjäll, & Mertz, 2008). When applied to the ADHD group, it could be that the observed numerical proficiencies are the result of a cognitive affinity for processing numeracies in the default stage of processing. However, longer latencies on conflict problems for the ADHD group relative to the control group (Figures 9 and 10) would not support a claim of numerical proficiency for ADHD reasoners. Peters et al. (2006) note that numerate reasoners are more deliberate in numerical comparisons, use appropriate numerical principles when comparing probabilities, and are less vulnerable to being misled by tempting, but non-relevant, information. However, average accuracy on the CRT task (on par with the control group) does not suggest that ADHD reasoners have anything beyond average skills in numerical reasoning.

The ADHD group's demonstrated style of numerical reasoning is unlikely to be attributed to higher cognitive capacity, as Thompson and Johnson (2014) and Thompson et al. (in press) observed in their studies of high capacity reasoners. Results are generally mixed regarding differences in general intelligence for individuals with ADHD, but if anything, an argument can be made for lower cognitive capacity, not higher, most notably with respect to fluid reasoning (Barkley, 1997b). Bridgett and Walker's (2006) meta-analytic review of intellectual differences between adults with and without ADHD found that differences on Wechsler Adult Intelligence Scale (WAIS) intelligence tests between ADHD and non-ADHD adults were small and not clinically meaningful. However, the presence of a comorbid disorder put ADHD adults more at risk for lower general intellectual ability relative to non-ADHD adults. Thus, based on the random sample of ADHD university students, it is unlikely that the results demonstrating ADHD reasoners to be significantly better at analytic reasoning were due to higher cognitive capacity.

Adherence to Instructions

Various explanations for this unexpected phenomenon must be ruled out before any implications of the results can be considered. There is no evidence that ADHD reasoners were successful at reasoning tasks under the statistic instruction because they are generally better at following instructions. In that case, ADHD reasoners would have surpassed controls under both the belief and response instruction; instead, they were better in decision-making only under the statistic instruction.

ADHD and Hyper-focusing

One could argue that these results fit with the contention that individuals with ADHD have the ability to hyper-focus on a task when it is interesting or engaging. Take for example, the ADHD child who can focus for length periods on a stimulating computer game, oblivious to the world around him. This phenomenon of hyper-focusing is common to individuals with ADHD, to the point where they are unconscious of their surroundings when they are doing something they really enjoy (Johnson-Quan, 2014). They may focus on a task so intensely that they are in a trance-like state, wherein they are not distractible and can often get a tremendous amount of work done. Schuck and Crinella (2005) observe that under conditions that minimize distractions, a student with ADHD can often solve complex problems better than he or she performs on simple laboratory tests of executive function. As the participants self-selected into the study by responding to advertisements, ADHD volunteers may have been highly motivated to participate in a reasoning study. This argument, though, does not account for the asymmetrical performance of ADHD reasoners between instruction conditions.

Assessment Measures of Rationality

One factor that we may be missing in educational pedagogies as well as psycho-educational assessment and evaluation is attention to the malleability of problem-solving through learned reasoning strategies. Stanovich, West, and Toplak (2012) and Stanovich and Stanovich (2010) argue that the ability to reason rationally requires three mental qualities: (a) an algorithmic-level cognitive capacity is required in order for inhibition and decontextualization activities to be sustained; (b) a reflective mind, characterized by the tendency to override inappropriate responses generated by the autonomous mind and to initiate deeper thinking that will produce a more optimal response; and (c) possession of cognitive mindware that allows the computation of a rational response.

Gaps in mindware are most easily remediable, as these gaps are entirely due to missing strategies and declarative knowledge, both of which can be taught (Stanovich & Stanovich, 2010). It is possible that ADHD reasoners are aware of their cognitive limitations and consistently depend on mindware skills of strategy use to mitigate executive function deficits, at least as demonstrated in this study.

Traditional quantitative psychometric measures, such as the Wechsler Intelligence Scale for Children (WISC) and the Wechsler Adult Intelligence Scale (WAIS) have failed us when it comes to evaluations of rationality (Stanovich, 2009; Stanovich & Stanovich, 2010). Existing intelligence tests based on Gf/Gc theory – derived from the Cattell/Horn/Carroll (CHC) theory of intelligence (Carroll, 1993) – postulate that tests of intelligence tap a small number of broad factors, two of which are dominant – fluid reasoning (Gf) and crystallized intelligence (Gc). These tests measure algorithmic level cognitive capacity or computational efficiency, but not the tendency for rational thinking, or rationality (Stanovich, 2009, Stanovich & Stanovich, 2010; Stanovich et al., 2012). Thus, we may be missing an important area of evaluation when assessing individuals with ADHD. Tests of fluid reasoning (often the Raven matrices) measure the computational ability of the algorithmic mind to sustain decoupling, but do not measure one's proclivity or ability to inhibit a prepotent response or measure the *mindware* tools mentally available to an individual. With respect to fluid intelligence, the mindware of rational thought clusters around domains of probabilistic, causal, and scientific reasoning (see Stanovich, 2009), whereas subtests of crystallized intelligence assess vocabulary, verbal comprehension domains, and general knowledge on very broad areas. Thus, traditional measures of fluid reasoning evaluate rationality only indirectly and to a small extent, whereas measures of crystallized intelligence do not evaluate individual differences of rationality to any degree.

PASS Theory

A clearer understanding of how the ADHD brain functions with respect to strategy use might be explained within the framework of the PASS theory of executive functioning (Das, Naglieri, & Kirby, 1994). This model of executive control is based on the seminal writings of A.R. Luria (1980) and his observations of brain-injured patients. Originally conceived by Das, Kar, and Parrila (1996), the PASS theory of intelligence holds that cognitive functioning consists of multiple domains that reflect the interaction of the individual's biological predispositions with the environment and cultural context. The PASS model organizes cognition within four primary areas of the brain: Planning, Attention, Simultaneous Processing, and Successive Processing (PASS). Emerging research holds promise for a measurement tool of cognitive *processes* using the Cognitive Assessment Tool (CAS; Das et al., 1994; Naglieri & Das, 1997, 2002, 2005) rather than conventional intelligence tests of the WISC and WAIS that assess cognitive *abilities*. Grounded in PASS theory, the CAS is designed to assess cognitive *processes* as characterized by the PASS theory: planning, attention, simultaneous processing, and successive processing. This novel approach to understanding brain function may provide a more accurate cognitive assessment of individuals with executive functioning deficits.

As described by Naglieri and Das (1997, 2002, 2005), the first system, planning, is located in the frontal lobes and involves executive functions responsible for controlling and organizing behaviour, selecting and constructing strategies, problem-solving, and monitoring performance. The second system, attention, is managed by broad areas of the frontal lobe as well as lower parts of the cortex and the parietal lobes. This brain region regulates attention and is responsible for maintaining arousal levels and alertness and ensuring focus on relevant stimuli. A third system of information processing occurs in the posterior region or the back of the brain and involves two processes to encode, transform, and retain information. Simultaneous processing is engaged when the relationship between items and their integration into whole units of information is required, such as recognizing figures or understanding the context of a sentence as a whole (e.g., a circle within a square vs. a square within a circle, or the difference between 'he had a shower before breakfast' and 'he had breakfast before a shower.') Lastly, successive processing is required for organizing separate items in a sequence, such as remembering a sequence of words or actions exactly in the order in which they had just been presented. Simultaneous processing is largely associated with the occipital and the parietal lobes while successive processing is generally associated with the frontal-temporal lobes.

It is the first system of cognitive operation, planning, that is most relevant to this study and the findings. If ADHD is an impairment of self-regulation assumed to be governed by prefrontal lobe functions (Goldberg, 2001), than a connection between the disorder and the conceptualization of cognitive process under the theoretical framework of PASS can be made. Goldberg describes ADHD executive dysfunction in the planning region as “poor planning and foresight, combined with diminished impulse control and exaggerated affective volatility” (p. 179). PASS profiles studied on children with ADHD using the CAS support the existing view that ADHD-C is more of dysfunction with executive processes of self-regulation than attention (Barkley, 1997b). Paolitto (1999) compared children with ADHD to those without and found that children with ADHD-C received significantly lower scores on the CAS Planning Scale than those without. Similarly, Naglieri, Goldstein, Iseman, and Schwebach (2003) also found that children with ADHD demonstrated reliably lower scores on the Planning Scale of the CAS and, notably, were observed to have a dissimilar PASS profile than children diagnosed with anxiety disorders (for a review, see Naglieri, 2005). More recently, similar findings of low scores on the Planning Scale of the CAS have been replicated with Dutch children by Van Luit, Kroesbergen, and Naglieri (2005). When contrasted against PASS profiles reported for children with low scores only on scales of Successive Processing, such as those with reading disorders and children with anxiety (no weaknesses revealed on PASS profile), there appears to be strong support for a PASS profile that is specific to individuals with ADHD.

Although all PASS processes are related to achievement, specific processes, such as planning, appear to be related to distinct aspects of academic performance, such as numerical concepts, number estimation and calculations (Das et al., 1994; Kroesbergen, Van Luit, & Naglieri (2003). The underpinning theory behind this concept is that planning processes are used to make decisions to solve math problems, to monitor performance of problem-solving, to recall numerical information and math facts, and to evaluate answers (Naglieri & Das, 1997). If executive processes of planning are known to be deficient in ADHD and this frontal component is broadly linked to knowledge of numerical concepts, perhaps strategic interventions based on numeracies can be successfully used to compensate for deficits.

Utility of PASS Theory as a Measure of Cognitive Abilities of Processing

Researchers have also studied the utility of the PASS theory, as operationalized by the CAS, as a useful tool in assessment and identification of children with ADHD. Naglieri et al. (2004) studied this possibility by investigating whether children with reported attention problems would evidence differences in CAS Planning Scales than typically developing children, and whether children with a reading disability would perform differently in successive processing abilities relative to those with a reading disability. As expected, Naglieri et al. (2004) found that children referred for attention problems earned lower scores on CAS Planning Scales and children diagnosed with reading disabilities scored lower on CAS Successive Processing Scales, whereas typically developing children earned similarly average scores in both areas. This finding suggests that Planning and Successive Processing Scales may hold some utility as part of a procedure for identification of ADHD and learning disabilities. This is encouraging research, as children with cognitive weakness in any one of the postulated four PASS processes are more likely to experience academic problems as compared to children without PASS weaknesses (Naglieri et al., 2004); thus, this type of assessment and identification is critically needed.

Strategy Training for Students with ADHD

ADHD is a disorder of inadequate response inhibition – a problem of performance, not skill; a problem of consistency, not ability (Goldstein & Naglieri, 2008). Higher estimates occurring ostensibly from persistent and consistent strategy use by ADHD reasoners when resolving conflict with statistics appear similar to improvements seen in math intervention studies that focus on the planning component of the PASS theory. These investigations have shown that students with ADHD and/or learning disabilities can be taught to better utilize their planning ability to be more strategic when completing math tasks, and that the facilitation of these tactics improves academic performance. The research originated with studies by Cormier, Carlson, and Das (1990) and Kar, Dash, Das, and Carlson (1993), who exposed children to strategy use in analytic math reasoning and then followed up with discussions on strategy use in problem-solving. Those children who performed poorly on measures of planning as per CAS testing methods were observed to have significantly greater gains than those with higher CAS planning scores. That is to say, children with a planning weakness profited significantly more from the strategy instruction than children without planning deficits. Carraher, Carraher, and Schliemann (1985) found this same result when offering strategic training to middle school student with learning disabilities. Students received both schema strategy training and problem-solving training, leading to substantially increased base-line math scores, which in turn generalized to other novel math word problem-solving. Further studies by Naglieri and Gottling (1995, 1997) reported similar conclusions in their study on strategy training for math problem-solving in learning disabled students. As with Carraher et al. (1985), these students showed markedly improved performance from base-line scores in analytic reasoning on math calculations after receiving comprehensive strategy training. Naglieri and Johnson (2000) extended this work. They reported that children with a cognitive weakness in planning improved considerably over base-line rates when strategies were taught, whereas those with no planning deficits improved only marginally in math performance with the same teaching intervention. More recently, Iseman and Naglieri (2011) compared regular instruction to strategy training for two groups diagnosed with ADHD. Those who received the strategic instruction method consistently outperformed the regular instruction group on math worksheets. This study, in particular, demonstrates that strategy training to support deficit planning processes may be beneficial to students with ADHD.

Another study by Deaño, Alfonso, and Das (2015) strengthens the argument of strategy use. Deaño and colleagues implemented a PASS Remedial Program (PREP) to examine potential improvement in children with special educational needs when strategies were aimed at specific cognitive processes underlying academic skills, such as arithmetic skills. Children who received training in the program were assessed at pre- and post-intervention in the PASS cognitive processes. They were also assessed for general levels of intelligence and arithmetic performance in calculus and math problem-solving. The program emphasized the development of strategies, such as rehearsal, sequencing, categorization, relation, seriation, procedural problem-solving, and rapid number estimation. Students were encouraged to become aware of strategy use through verbalization of their problem-solving approach. In line with previous studies, differences in pre-and post-testing were significantly higher for children from the experimental group (special educational needs) with respect to planning processes, arithmetic skills, and math problem solving as compared to controls. The rationale behind improvement when strategies are utilized for students with learning difficulties, in particular when learning strategies for math word problems is thus: As students become more proficient at using strategies, they become adept at solving problems because they use more efficient memory-based strategies and become experts at numerical decoding and valuation (Geary, 2004). As well, with increased practice in using strategies, it takes less time to execute each strategy. The transition to a more automated style of processing that is memory-based results in faster solutions, a reduction in valuable resources of working memory, and fewer procedural errors.

The conclusions of the current study regarding improved reasoning performance through persistent use of a strategy use align with research showing improvement though strategic instruction for students who have limited executive functions in areas of planning, as related to PASS theory. Research literature over the last ten years offers limited information relating to the efficacy of targeted interventions for students with ADHD, such as instruction on utilizing planning processes more efficiently, curbing impulsivity in decision-making, increasing reflection time in problem-solving, and ensuring appropriate application of strategies.

Practical Implications

ADHD is associated with chronic academic underachievement relative to the intellectual capabilities of those diagnosed, including low grades at school and low scores on standardized tests (Barkley, 2014; Bussing et al., 2012; Loe & Feldman, 2007; Schuck & Crinella, 2005) and a higher risk of adolescent school dropout (32%–38% vs.5%; Barkley, 2002, 2006; National Center for Educational Statistics [NCES], 2006). Many individuals with ADHD either drop out or disengage in their schooling, keeping them away from many post-secondary options (Barkley, 2014; Bussing et al., 2012; Loe & Feldman, 2007; Schuck & Crinella, 2005). There is a critical need for collaboration between science, psychology, and education to inform teaching methods that engender a positive and rewarding learning experience for all students of diverse needs. By integrating our knowledge of cognition and reasoning with what is known about the biological and neuropsychological underpinnings of ADHD, we can better design pedagogies centered on brain-based approaches to learning in order that students of diverse needs, including those with ADHD, can process the experiences in ways that augment the extraction of meaning. The current study's surprising results underscore how acknowledged executive impairments associated with ADHD can hinder the reasoning process for students diagnosed with this disorder. The impact of impairments in a classroom setting, such as when writing a multiple exam, are numerous. First, students with ADHD may find it more difficult than their non-

ADHD peers to encode and retain wordy or protracted information; second, students with ADHD are likely to have more difficulty inhibiting the tempting but incorrect answers designed to catch students on multiple choice exams; and third; equal or better accuracy rates and similar levels of confidence between groups evidence that students with ADHD are quite capable of overcoming both inhibitory deficits and working memory shortfalls if given additional time to produce a response. Moreover, if teachers are aware of the specific difficulties with inhibitory control and working memory shortfalls, they may use alternate means when teaching students with ADHD (e.g., information presented in bullet form, concise sentences, everyday language, clear-cut explicit statements, and content containing instantly recognizable meanings).

Strategy Instruction. Explicit systematic instruction has been identified as one of the strongest evidence-based approaches to instruction for students with learning disabilities and ADHD (Allsopp, Minskoff, & Bolt, 2005). The possibility that university students with ADHD consistently and persistently applied a strategy for problem-solving to a greater extent than their non-ADHD counterparts underscores three points: a) that individuals with ADHD are aware of their cognitive limitations; b) that individuals with ADHD are capable of learning and implementing strategies intended to assist them in problem-solving; and c) that there is a potential for over-reliance on these strategies. Allsopp and colleagues report that students with ADHD and learning disabilities often have difficulty applying learning strategies on their own; however, when provided strategy instruction that is explicit and systematic, students can learn to apply strategies proficiently. A unique individualized course-specific strategy instruction model was developed by Allsopp and colleagues to assist postsecondary students with learning disabilities and ADHD in their learning needs and increase success in meeting rigorous academic demands. Allsopp et al.'s model, which was tested over a three year period, included the following components: (a) informal assessment of a student's individual learning needs, coupled with a learning strategy intervention (e.g., organization, test taking, study skills, note taking, reading, and writing); (b) targeted strategies that addressed the learning need as applied to specific course demands; (c) instruction of learning strategies using systematic explicit instruction within the context of a particular course; and (d) one-on-one strategy instruction tailored to the student's learning needs. The three-year project resulted in increased GPAs and increased academic performance for the majority of participants that was attributable, at least in part, to involvement in the strategy training project. In particular, a subgroup of students on academic probation or suspension seemed to receive maximum benefit from the strategy training. Moreover, participants sustained academic improvement one semester after strategy instruction ended.

Accommodations for Extra Time. Observed longer response latencies for participants with ADHD on both the CRT task and most conditions of base-rate task identify the necessity of extended time to complete tasks for students with ADHD. Even with the implementation of a numerical strategy, the ADHD group required significantly longer latencies than controls to resolve base-rate conflict problems with statistics, likely to overcome inhibitory deficits associated with ADHD. Response latencies for problems solved with beliefs, both for conflict and non-conflict problems, also required longer response latencies for the ADHD group, possibly due to reduced overall efficiency in terms of working memory, processing speed, and task fluency (Holmes et al., 2010; Lewandowski et al., 2007), resulting in significant difficulty to encode the lengthy descriptions. Regardless of the underlying reason, the revealed longer latencies support the critical need for time accommodations for students with ADHD on school course work and exams. Currently, most post-secondary schools offering disability support for students with ADHD provide accommodations of time of one-half for exams or assignments. The longer latencies demonstrated in the current study substantiate that this additional time may be vital to the academic success and progress of students with ADHD.

Implications for Secondary School. Future studies should be completed to determine if the current findings apply to younger ages and/or individuals with ADHD not enrolled in post-secondary education. The implications of these findings are extensive with respect to academic outcomes for younger students, such as those in high school. The notion that individuals with ADHD may perform better when highly salient information is readily accessible might influence instruction, material presentation, or assignment rubrics for grades in secondary school.

Education about the Cognitive Limitations of ADHD. Many educators agree that the training they receive regarding interventions and strategies specific to instructing individuals with ADHD is inadequate (Martinussen, Tannock, & Chaban, 2011). If educators were provided a better understanding of the cognitive processing limitations of ADHD, it may influence how they interact, guide, and teach individuals diagnosed with the disorder. The findings of this study may provide a clearer understanding of why certain teaching tactics, such as explicit strategy instruction, are effective for students with ADHD (Meltzer & Montague, 2001) and why additional time to complete work is a necessity for ADHD students. Many classroom interventions for ADHD are geared toward behavioural modifications (e.g., grab their attention; make it relevant; do it together; try teams; take aim; keep it visual; talk out loud; build on what they know; modify assignment length; allow “wiggle cushions,” alternate high- and low-energy lessons, rearrange seating, Fulk, 2000). Specific targeted instructional interventions, such as strategy training, may facilitate even more academic success for the ADHD student. Teachers, parents, and the students themselves diagnosed with ADHD need to be educated about the executive inhibition deficits of ADHD in order to implement successful interventions and strategies designed to overcome deficits.

Limitations

Considering that inhibitory deficits were only manifested in response latencies, an obvious limitation may be that the base-rate and CRT task, both assumed to be a proxy measure of executive inhibition, may not have been ideal study tasks with which to examine inhibitory deficits in an ADHD population. Future studies that utilize logic problems well-evidenced to measure inhibitory control, such as syllogisms, are warranted.

Participants were asked to specify which college they were registered in (e.g., Arts & Science; Nursing; Engineering); however, in view of the surprising findings, a more specific taxonomy of participants’ majors would have been advantageous. Frequency tables (see Table 4) illustrate that the dominant college of enrollment for participants was Arts and Science; however, this broad categorization was unhelpful when making associations between academic majors that require a high proficiency with numbers (e.g., math, physics, chemistry) and cost-efficient cognitive strategies for problem-solving with numerical strategies. Recording the specific majors of each participant should be a consideration for future studies of this nature to correlate academic interest with reasoning performance.

It is quite possible that the participant pool of ADHD students have higher intellectual capacities than that of non-university students with ADHD, which could diminish the generalizability of the results. IQ scores of university students differ greatly between majors, but as a whole, differences in IQ scores are positively correlated with academic achievement or levels of education (Barber, 2005; Deary, Smith, & Fernandes, 2007; Kaufman, Reynolds, Liu, Kaufman, & McGrew, 2012). The education–intelligence correlation is likely reciprocal: schooling raises intelligence and intelligent people realize the advantages to be gained through higher education (Rindermann, 2008). Just as with the general population, individuals diagnosed with ADHD who are afforded higher levels of intelligence often achieve success that is out of reach for those ADHD individuals with lower IQs (Loe & Feldman, 2007), and this advantage certainly applies to the opportunity for university studies. Thus, reasoning performances by ADHD participants may not necessarily extend to the subset of ADHD individuals in the general population who do not attend university.

It is also possible that the study's sample university students with ADHD were able to practice and hone their reasoning skills early on in education, whereas students with ADHD who did not have the potential to attend university may not have had the capability to do strategic problem-solving while in secondary education. Alternatively, given that education and complex tasks are known to raise levels of intelligence and knowledge (Rindermann, 2008), perhaps the additional years of university education provided ADHD students with more opportunities to enhance their strategy skills. Taken one step further, we do not know the particular academic success of the ADHD participants. Certainly the ADHD group's latency scores indicate that individuals with ADHD are not as fast in academic reasoning as their counterparts, but this does not necessarily translate to lower grade point averages. Sternberg (1998) proposes that performance on both tests of intelligence and academic achievement is mediated by developing expertise in meta-cognitive skills, learning skills, and thinking skills. It is these developing thinking skills that this study speaks to. Given the association between ADHD and executive functioning, perhaps potential university contenders diagnosed with ADHD may have found strategic ways to augment executive skills in numerical problem-solving, thereby increasing their meta-cognitive skills, learning skills, and thinking skills. However, this does not necessarily translate to higher scores for intelligence.

It also is possible that the severity of attention deficits in our ADHD group were less than that seen in the general population of persons diagnosed ADHD. The extent of impairment would likely have implications for results, generalization, and future research.

There is also the possibility that the controlled environment of the reasoning lab made for ideal conditions for individuals with ADHD to maintain focus and concentration, much more so than for control participants. In ideal conditions that minimize the influence of inattentiveness (e.g., reduced distractions, high-interest stimuli), a student can solve complex problems at least as well—and usually better—than he or she performs on simple laboratory tests of executive function (Schuck & Crinella, 2005). While this advantage should have extended to all conditions, it is possible that laboratory effects were especially favorable to the ADHD group. Thus, it is not known if similar reasoning performance levels by individuals with ADHD could be attained in a typical classroom learning environment.

Future Directions

The chosen tasks for the current study's experiment may not have sufficiently measured executive inhibition and its effect on high-level reasoning. Future studies could examine this relationship using other forms of logic tasks that are perhaps more suitable for measurement of inhibitory control. This could include syllogism tasks, the most commonly accepted form of logical reasoning, wherein reasoners must decouple logic from established truth to assess the validity of an argument. Examples include: conditional syllogisms (e.g., If Johnny is eating sweets every day, he is placing himself at risk for diabetes. Johnny does not eat sweets every day. Therefore Johnny is not placing himself at risk for diabetes.); disjunctive syllogisms (e.g., Either the meeting is at school or at home. The meeting is not at home. Therefore the meeting is at school.); or categorical syllogisms (e.g., All men are mortal. Socrates is a man. Socrates is mortal.).

Future replication studies are necessary to confirm the hypothesis of strategy use by ADHD thinkers and their difficulty in processing lengthy expanses of information. Hypothesis testing might include having participants reason on assorted logic/probability problems, a portion of which enable low-cost processing and others that demand heavy cognitive resources to separate logic from truth. Specifically, problem-solving abilities can be contrasted between problems that feature salient numbers (e.g., base-rate problems and denominator neglect tasks) against syllogism tasks (e.g., categorical syllogism tasks and conjunction fallacy tasks). If the strategy hypothesis is correct, ADHD reasoners should reveal better performance on the problems containing numerical information as compared to non-numerical tasks that demand more complex cognitive reasoning to separate belief from logic.

One way to examine if ADHD reasoners have difficulty encoding lengthy descriptive information when asked to reason with beliefs is to replicate the current experiment using base-rate problems that feature "bullet-points" as opposed to a "paragraph form" presentation of the descriptive information. This format replicates an experiment done by Pennycook, Fugelsang, and Koehler (2015) and may result in better performances for ADHD reasoners when solving problems under the belief instruction.

Another question that could be addressed is to determine if younger age groups diagnosed with ADHD also utilize numerical strategies. Comparative studies could be addressed through a two-stage process that examines both adults and adolescents with and without ADHD using the selected logic/probability tasks described above.

An innovative method to shed further light on how ADHD students approach problem-solving tasks is to track eye movements as participants work through logic/probability problems. Eye-tracking software follows eye movements to assess what detail of the problem reasoners are focusing on in decision-making, which would help to confirm if and when strategies are applied. As well, eye-tracking software would be beneficial to determine how quickly/slowly/carefully the ADHD reasoners are reading (and thus encoding) the descriptive information in all problem conditions. Further measures that could be incorporated in future studies of this type would be the inclusion of standardized measures of IQ to compare individual differences of cognition as well as a thinking disposition questionnaire to reveal potential correlations between cognitive capacity and normative answers.

Conclusions

Accuracy rates for the experimental task of the CRT did not appear to manifest the omnipresent executive inhibition difficulties widely evidenced to be a core deficit in ADHD. One explanation may be that inhibitory deficits are manifested in longer response latencies observed for ADHD reasoners. Thus, ADHD reasoners require additional time to successfully engage the inhibitory control, but given this time, they can perform as accurately as controls.

A second similar finding was that the characteristic inhibitory deficits of ADHD reasoners were not evidenced in responses by ADHD reasoners when resolving conflict base-rate problems, as revealed by the ADHD group's superior performance relative to controls. Moreover, against tenets of serial model processing, two-way interference was observed on conflict conditions for the base-rate problems. This supports literature demonstrating that extreme base-rates (e.g., 997 vs. 3), such as used in this study, are accessible to Type 1 processes. Consistent with previous evidence (De Neys, 2007, 2012; Pennycook et al., 2014; Pennycook & Thompson, 2012), it may be possible that Type 1 processes stream multiple outputs based on both intuitive probability and beliefs. As with the CRT task, it is likely that inhibitory deficits were manifested by the ADHD group as longer RTs relative to controls when solving conflict problems. Thus, although base-rates appear to be accessible to Type 1 processing (as evidenced by two-way interference in controls), Type 2 processing may still be required to resolve the conflict between base-rates and beliefs. Thus, while the ADHD group was ultimately able to successfully inhibit the inappropriate response (as evidenced by accuracy rates), they required significantly longer latencies to do so.

A third key conclusion was that, while both groups appear to have used a low-cost numerical strategy to solve problems with statistics, the ADHD reasoners appear to have relied more consistently and persistently on this strategy, likely to mitigate executive deficits. This implies that the current study's sample of ADHD students are (a) aware of cognitive deficits; (b) have discovered strategic methods to cope with these executive function constraints; and (c) depend heavily on these coping methods for problem-solving.

Consistent with literature citing working memory and processing speed inefficiencies in ADHD (Au et al., 2014; Holmes et al., 2010; Lewandowski, et al., 2007; Martinussen et al., 2005; Willcutt et al., 2012), the current study's ADHD participants appeared to have considerable difficulty processing the prolix descriptions, as indicated by similar RTs observed for the ADHD group in all problems solved with beliefs, regardless of the congruency of the problem. This has important implications for classroom instruction, as does the finding that, despite having comparable or better accuracy in problem-solving relative to controls, ADHD reasoners still required significantly longer latencies to solve problems in most conditions, observations that clearly support the need for accommodations of time extensions for academic work.

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Table 1

Classic Executive Function Tasks used in Neuropsychological and Cognitive Studies of ADHD[5]

Task Description	**Description**
Matching Familiar Figures Test	The Matching Familiar Figures Test is a classic cognitive test. The child views a series of visual designs. On the page is a target design and a number of to-be-matched designs. The task is to correctly match the target with its identical mate within the group of designs. The designs are more difficult to identify as the task progresses, so that controls slow down to main accuracy on the later items. Failure to slow down, combined with increased errors, is taken as failure of inhibitory control or "impulsivity."
Continuous Performance Test	The Continuous Performance Test (CPT) has several varieties. Their common element concerns the ability to respond to a rare target over a period of extended time (15 min or longer). For example, the computer might show a different letter every 2 sec; however, when an "X" appears that was preceded by an "A" the child is to press the response button. The target will appear only on 25% or less of trials. Successful detection of a rare target amid many nontargets is an index of vigilance. Signal detection theory can be used to compute a parameter called d-prime (D =), which combines hits and misses to calculate sensitivity to the signal. One can also look at the relative weighing of commissions and omissions and calculate a parameter called beta, which signifies the response bias (e.g., tends to overrespond or underrespond).
Basic Go/No-Go	The inverse of a CPT, one must withhold response on rare "no-go" trials. Randomly alternating stimuli are presented (e.g., an "A" and a "B," or two different visual designs). The child is instructed to make a response when he or she sees the "A" but not when he or she sees the "B." The "A" is presented more often to create a response set or prepotency toward responding. Errors in response to the "B" are taken as an index of failed inhibitory control.
Event Rate Go/No-Go	In the "event rate" version of this task, the rate at which stimuli are presented is varied (e.g., every 1 sec, every 4 sec, and every 8 sec). The faster even rates are more "activating" for the child up to an optimum, then become too fast and lead to performance decline. Thus, in general, a child with ADHD is expected to approach normal performance more closely at the faster event rates.
Motivated Go/No-Go	The task is similar to the basic go/no-go listed above, except that more stimuli are used (e.g., several numbers), some of which are paired with a reward (if you press the key when you see the "A," you win 25 cents, and some with a response cost or punishment (if you press the key when you see a "B," you lose 25 cents. Various configurations of rewards or punishments are possible.

[5] Adapted *from Nigg, 2001, 2005*

Task Description	Description
Stop Task	Presents equally probable stimuli (e.g., an “X” and an “O”) with the instruction to press a corresponding key as quickly as possible, depending on which letter appears, creating a prepotent tendency to respond on most trials. On a minority of trials (25% typically), a signal (e.g., a tone) indicates that the child is not to respond. Timing of the tone is varied to estimate the speed of the “inhibition process” (essentially, how much warning does the child need to interrupt the response, which is mathematically independent of the speed of the response output process). Physiologic data indicate that a central (cognitive) process and a peripheral motor process are involved; responses can be interrupted even after peripheral nerves (on arm and hand muscles) have begun to fire. To measure inhibitory ability, older versions of the task calculated stop signal reaction time (SSRT) slope (degree of success drop-off at preset warning intervals). Newer versions use a dynamic tracking algorithm to directly estimate SSRT or warning time needed. The “go” trials of the task provide a strong measure of rapid decision-response time, and the variability of those response times is an index of response variability.
Stroop Task	This classic task has two or three conditions, depending on the design. The usual control condition is to name aloud as fast as possible the ink color of rows of x’s (e.g., xxxx printed in red, green, and blue ink). Speed on this task is compared with speed on the interference task. In the latter, the child must name as fast as possible the ink color of a sequence of words, each of which is a color word different from the color of the ink (e.g., the word “red” printed in blue ink, the word “blue” printed in green ink). Because reading the word is a faster, more automatic process than naming the color, normal children and adults are slower to name the colors in the interference condition; the extent of this slowing versus the control condition is taken as an index of the effectiveness of an interference suppression mechanism. A range of related stimulus incompatibility tasks tap interference control without requiring reading. Directed Forgetting This task is widely used in cognitive psychology but as yet little investigated with ADHD. The child views a sequence of easily named pictures and is then told to forget that list. They then view a second list, which they are told to remember. Recall of words to be remembered and words to be forgotten is then examined, across varying mixes of these conditions. In general, failure to recall a normal number of “remember” words or excess recall of “forget” words is taken as inhibitor failure.
Emotional Stroop	Similar to the Stroop, except that instead of color words, emotionally evocative words, such as words associated with anxiety or with fears, are printed in colored ink and must be named. Anxious participants are slowed down more by anxiety-associated words than by neutral words, interpreted as difficulty suppressing the association to those words.

Task Description	Description
Flanker Task	A type of selective attention task that can be designed to require perceptual or cognitive suppression of competing information. Similar to Stroop, except information is spatially distinct. For example, the child would view a target area in the center of a computer screen, with an instruction to press the corresponding key depending on whether the “X” or “N” appears in the center. Immediately adjacent to the center letter are two “flanking” distractor letters that are to be ignored. The flankers can be incompatible (X or N) or neutral (e.g., F or D). It takes longer to respond to XNX than to FNF because in the first instance the flanker is a possible response that must be suppressed.
Iowa Gambling Task	The Iowa gambling task (IGT) is a test originally meant to measure decision making specifically within individuals who have ventromedial prefrontal cortex damage. The concept of impulsivity as relates to the IGT is one in which impulsive decisions are a function of an individual's lack of ability to make rational decisions over time due to an over amplification of emotional/somatic reward. In the IGT individuals are provided four decks of cards to choose from. Two of these decks provide much higher rewards but the deductions are also much higher while the second two decks have lower rewards per card but also much lower deductions. Over time anyone who chooses predominantly from the high rewards decks will lose money while those who choose from the smaller rewards decks will gain money.
Card playing/door opening	Each card played either wins or loses money. Early in the “game,” most cards win money, creating a reward-based response set to keep playing. As the game progresses, the probability that the cards will lose money increases. Normal respondents at some point realize this and stop playing before they have lost all the “winnings.” Impulsive participants play longer and lose more money. This is thought to demonstrate failure to suppress the reward-based response set when punishments appear. The door opening task is the same, except doors and opened instead of playing cards; thus, it is more appropriate for younger children.
Wisconsin Card Sorting Test	The Wisconsin Card Sort is a classic “executive function” measure. The child must match a series of cards to a target card; cards include varying numbers of shapes, varying shapes, and varying colors. Thus, the child must decide whether to sort by color, by number, or by shape. After 10 consecutive correct matches, the sorting rule changes, but the child is not told of the change. Thus, they must notice that the old rule is no longer working, determine the new rule, and again this continues for 10 correct matches, up to a total of six categories (in the full-length version of the test). The test requires working memory, abstraction, and set shifting abilities and activates prefrontal cortex.

Task Description	Description
Tower Task	Several tower tasks exist, including the Tower of London, the Tower of Hanoi, the Stockings of Cambridge, and others. The idea in all of them is that discs or balls must be moved around on pegs (either manually or on a computer screen) according to certain rules, to arrive at a predetermined arrangement. The task required visualizing the moves in advance and can be designed to place heavy loads on visual working memory and sequencing.
Directed Forgetting	This task is widely used in cognitive psychology but as yet little investigated with ADHD. The child views a sequence of easily named pictures and is then told to forget that list. They then view a second list, which they are told to remember. Recall of words to be remembered and words to be forgotten is then examined, across varying mixes of these conditions. In general, failure to recall a normal number of "remember" words or excess recall of "forget" words is taken as inhibitory failure.
Negative Priming	An important variant of selective attention measures, this task has several versions, all of which exploit the principle that when two stimuli appear that differ on the task-relevant property (e.g., presented with a red car and a blue house, name the red object), the unchosen object property tends to act as though it has been suppressed, in that on the next trial it would take longer to name the red house, because the house had been suppressed on the prior trial, versus if the prior trial had not included a house. Failure to show this normal delay to name the previously "cued-wrong" object is taken by some as evidence of failure in an attentional inhibitory process.
Prepulse Eyeblink	An automatic startle eye blink response evoked by a loud noise is partially suppressed if the startling event (e.g., the loud noise) is preceded by another stimulus. The degree of this suppression is the inhibitory index. The effect is automatic and is thought to be related to brainstem and subcortical functioning involving dopaminergic neural systems.
Attentional Orienting/ Spatial Orienting	In this task, the child fixes his or her eyes on the centre of the computer screen, with an instruction to press the key as quickly as possible when he or she sees the target appear in either the left or the right periphery. The target is preceded by a warning cue that is either correct or incorrect in its spatial (left or right) visual field location. The degree to which reaction time to the target is slowed down by the incorrect warning cue is sometimes interpreted as an index of inhibitory control, although that reaction time slowing could also be due to failure of several possible attentional mechanisms other than inhibition. To avoid this, the task can, in principle, be designed to tap three kinds of inhibition, according to Rafal and Henik (1994); (a) inhibition of orienting to unattended locations (automatic), (b) inhibition of reflexive orienting in the service of a goal (controlled-effortful), and (c) inhibition of return (automatic). Most studies of ADHD were not designed to isolate the three basic inhibition functions, but rather to examine attentional orienting.

Task Description	Description
Oculomotor Inhibition of Return	This is a variant of the orienting task, but includes eye movement monitoring. Eye movements are observed while the person views the centre of the computer screen. Sudden onsets of objects appear in various parts of the screen, creating a reflex response to move the eyes toward the object. In normal adults, the eyes are slower to return to a location that was recently visited than to a novel location. Failure to show this normal slower response to a previously viewed location is taken as a failure of this automatic inhibition process. Because attention is known to move prior to the eyes (at a millisecond level), reaction time calculations are thought to enable a distinction between attentional and oculomotor inhibition of return.
Antisaccade	Oculomotor task in which eye movements are monitored. On each trial, a signal appears in the visual periphery, creating a reflex response to move the eyes toward that signal. The reflex is difficult to resist. On some blocks of trials, children are told not to move their eyes toward the signal. Instead, they might be instructed to delay their response or to move their eyes away from the signal. Errors toward the signal, as well as presignal anticipations, are taken as indices of inhibitory ability or ability to suppress motor response.

Table 2

DSM-5 diagnostic criteria for Attention Deficit/Hyperactivity Disorder (ADHD) [6]

A. A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, as characterized by (1) and/or (2)

   1. **Inattention:** Six (or more) of the following symptoms have persisted for at least six months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

      Note: The symptoms are not solely a manifestation of oppositional behaviour, defiance, hostility, or failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

      a. Often fails to give close attention to details or makes careless mistakes in schoolwork, at work, or during other activities (e.g. overlooks or misses details, work is inaccurate).
      b. Often has difficulties sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations, or lengthy reading).
      c. Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction).
      d. Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (e.g., starts tasks but quickly loses focus and is easily sidetracked).
      e. Often has difficulty organizing tasks and activities (e.g., difficulty managing sequential tasks; difficulty keeping materials and belongings in order; messy, disorganized work; has poor time management; fails to meet deadlines).
      f. Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adolescents and adults, preparing reports, completing forms, reviewing lengthy papers).

[6] Reprinted with permission from the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, (Copyright 2013, pp. 59–60). American Psychiatric Association.

g. Often loses things necessary for tasks or activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses, mobile telephones).
h. Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts).
i. Is often forgetful in daily activities (e.g., doing chores, running errands; for older adolescents and adults, returning calls, paying bills, keeping appointments).

2. **Hyperactivity and Impulsivity:** Six (or more) of the following symptoms have persisted for at least six months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

Note: The symptoms are not solely a manifestation of oppositional behaviour, defiance, hostility, or a failure to understand tasks or instructions. For older adolescence and adults (age 17 and older), at least five symptoms are required.

a. Often fidgets with or taps hands or feet or squirms in seat.
b. Often leaves seat in situations when remaining seated is expected (e.g., leaves his or her place in the classroom, in the office or other workplace, or in other situations that require remaining in place).
c. Often runs about or climbs in situations where it is inappropriate (Note: in adolescents or adults, may be limited to feeling restless).
d. Often unable to play or engage in leisure activities quietly.
e. Is often "on the go," acting as if "driven by a motor" (e.g., is unable to be or uncomfortable being still for extended time, as in restaurants, meetings; may be experienced by others as being restless or difficult to keep up with).
f. Often talks excessively.
g. Often blurts out answers before a question has been completed (e.g., completes people's sentences; cannot wait for turn in conversation).
h. Often has difficulty waiting his or her turn (e.g., while waiting in line).
i. Often interrupts or intrudes on others (e.g., butts into conversations, games, or activities; may start using other people's things without asking or receiving permission; for adolescents and adults, may intrude into or take over what others are doing.

A. Several inattentive or hyperactive-impulsive symptoms were present prior to age 12 years.

B. Several inattentive or hyperactive-impulsive symptoms are present in two or more settings (e.g., at home, school, or work; with friends or relatives; in other activities).

C. There is clear evidence that the symptoms interfere with, or reduce the quality of, social, academic, or occupational functioning.

D. The symptoms do not occur exclusively during the course of schizophrenia or another psychotic disorder and are not better explained by another mental disorder (e.g., mood disorder, anxiety disorder, dissociative disorder, personality disorder, substance intoxication or withdrawal).

Specify whether:

Combined presentation: If both Criterion A1 (inattention) and Criterion A2 (hyperactivity-impulsivity) are met for the past six months.

Predominantly inattentive presentation: If Criterion A1 (inattention) is met but Criterion A2 (hyperactivity-impulsivity) is not met for the past six months.

Predominantly hyperactive/impulsive presentation: If Criterion A2 (hyperactivity-impulsivity) is met and Criterion A1 (inattention) is not met for the past six months.

Table 3

Demographical Information of Participants

	Males	Females	Total
Non-ADHD (Controls)	**21**	**43**	**64**
Age Range	19-53 years	19-59 years	
Age: Mean	26.3 years (SD = 7.23)	29.23 years (SD = 10.3)	
Age: Median	25 years	25 years	
Age: Mode	20 years	21 years	
Years of Study: Mean	4.1 years (SD = 2.68)	4.1 year (SD = 2.35)	
Years of Study: Median	4 years	4 years	
Years of Study: Mode	1 year	4 years	
College of Study: Mode	Arts and Science	Arts and Science	
Test Anxiety	1	0	
Learning Disability	0	0	
ADHD	**23**	**41**	**64**
Age Range	18-54 years	20-58	
Age: Mean	27.3 years (SD =9.3)	31.15 years (SD = 11.07)	
Age: Median	24 years	27 years	
Age: Mode	19 years 20 years 25 years	20 years	
Years of Study: Mean	4.13 years (SD = 4.21)	4.16 years (SD = 2.43)	
Years of Study: Median	3 years	4 years	
Years of Study: Mode	1 year 3 years 4 years	2 years	
College of Study: Mode**	Arts and Science	Arts and Science	
Test Anxiety	1	10	
Learning Disability	0	0	
Total	**44**	**84**	**128**

***see detailed list of College of Study next table*

Table 4

Detailed List of College of Study by Participants

Group	College	n	Group	College	n
Control Group	Arts and Science	28	**ADHD Group**	Arts and Science	27
	Education	2		Education	2
	Business	5		Business	4
	Engineering	5		Engineering	7
	Nursing	1		Nursing	7
	Kinesiology	3		Medicine	2
	Graduate Studies & Research	15		Social Work	2
	Agriculture	3		Kinesiology	1
	Other	2		Pharmacy and Nutrition	1
				Graduate Studies & Research	3
				Law	2
				Veterinary Medicine	2
				Other	4
	Total	**64**		**Total**	**64**

Table 5

Duration of Effects of Commonly Used ADHD Medications[7]

DRUG	FORM	DURATION OF EFFECTS
METHYLPHENIDATE		
RITALIN **METHYLIN** **METADATE** **Generic MPH**	Short Acting Tablet 5 mg 10 mg 20 mg	About 3-4 hours. Most helpful when need rapid onset and short duration.
FOCALIN **(with isolated dextroisomer)**	Short Acting Tablet 2.5 mg 5 mg 10 mg	About 3-4 hours. Most helpful when need rapid onset and short duration. Only formulation with isolated dextro-isomer.
RITALIN SR	Mid Acting Tablet 20mg	Onset delayed for 60-90 minutes. Duration supposed to be 6-8 hours, but can be quite individual and unreliable.
METHYLIN ER **METADATE ER**	Mid Acting Tablet 10 mg 20mg	
RITALIN LA ***50% immediate release beads and 50% delayed release beads***	Mid Acting Capsule 20 mg 30 mg 40 mg	Onset in 30-60 minutes. Duration about 8 hours.
METADATE CD ***30% immediate release and 70% delayed release beads***	Mid Acting Capsule 10 mg 20 mg 30 mg	
CONCERTA ***22% immediate release and 78% gradual release***	Long Acting Tablet 18 mg 27 mg 36 mg 54 mg	Onset in 30-60 minutes. Duration about 10-14 hours.

[7] *Adapted from Johnson & Parker, 2004*

Duration of Effects of Commonly Used ADHD Medications, continued

DRUG	FORM	DURATION OF EFFECTS
DEXTROAMPHETAMINE		
DEXTROSTAT	Short Acting Tablet 5 mg 10 mg	Onset in 30-60 minutes. Duration about 4-5 hours.
DEXEDRINE ***2004 PDR does not list short acting Dexedrine tablets**	Short Acting Tablet 5 mg	
DEXEDRINE SPANSULE	Long Acting Spansule 5 mg 10 mg 15 mg	Onset in 30-60 minutes. Duration about 5-10 hours.
dextroamphetamine sulfate ER	5mg 10 mg 15 mg	

MIXED AMPHETAMINE	FORM	DURATION OF EFFECTS
ADDERALL	Short Acting Tablet 5 mg 7.5 mg 10 mg 12.5 mg 15 mg 20 mg 30 mg	Onset in 30-60 minutes. Duration about 4-5 hours.
ADDERALL XR ***50% immediate release beads and 50% delayed release beads***	Long Acting Capsule 5 mg 10 mg 15 mg 20 mg 25 mg 30 mg	Onset in 60-90 minutes (possibly sooner). Duration 10-12 hours.

Duration of Effects of Commonly Used ADHD Medications, continued

DRUG	**FORM**	**DURATION OF EFFECTS**
ATOMOXETINE		
STRATTERA	Long Acting Capsule 10 mg 18 mg 25 mg 40 mg 60 mg	Starts working within a few days to one week, but full effect may not be evident for a month or more. Duration 10-12 hours as long as taken daily as directed.
BUPROPRION	**FORM**	**DURATION OF EFFECTS**
WELLBUTRIN IR	Short Acting Tablet IR-75 mg 100 mg	About 4-6 hours.
WELLBUTRIN SR	Long Acting Tablet SR-100 mg 150mg 200 mg	About 10-14 hours.
ALPHA-2 AGONISTS	**FORM**	**DURATION OF EFFECTS**
CATAPRES (clonidine) **------------------------------ CLONIDINE**	Tablet 0.1 mg 0.2 mg 0.3 mg -------- Tablet 0.1 mg 0.2 mg 0.3 mg	Onset in 30-60 minutes. Duration about 3 - 6 hours.
CATAPRES Patch	TTS-1 TTS-2 TTS-3	Duration 4-5 days, so avoids the vacillations in drug effect seen in tablets.
TENEX (guanfacine) **---------------------- guanfacine tablets**	1 mg 2 mg 3 mg -------- 1 mg 2 mg 3 mg	Duration about 6 - 12 hours.

Table 6

Mean Probability Estimates for Congruency x Instruction x Group (% accuracy)

Group		Statistics	Beliefs	Totals
Control	N	64	64	64
	Conflict	64.68	60.78	62.73
	SD	28.92	23.35	14.34
	SE	3.62	2.96	1.79
	N	62	63	61
	Non-Conflict	87.17	82.20	84.81
	SD	10.75	13.69	9.56
	SE	1.37	1.73	1.22
	N	62	63	61
	Mean Totals	76.02	71.40	73.63
	SD	16.44	12.48	9.54
	SE	2.09	1.57	1.22
ADHD	N	64	64	64
	Conflict	78.93	59.13	69.03
	SD	24.34	25.83	15.42
	SE	3.04	3.23	1.93
	N	63	63	62
	Non-Conflict	90.68	85.65	88.41
	SD	12.24	12.93	10.44
	SE	1.54	1.63	1.33
	N	63	63	62
	Mean Total	84.97	72.49	79.11
	SD	16.43	13.03	10.04
	SE	2.07	1.64	1.28

Group x Congruency x Instruction
$F(1,121) = 3.54$, $MSE = 536.04$, $p = .062$, $\eta_p^2 = .028$

Table 7

Mean Probability Estimates for Instruction x Group (% accuracy)

	Group		Statistics	Beliefs	Total
Instruction x Group	Control	N	62	63	61
		Mean	76.02	71.40	73.63
		SD	16.44	12.48	9.54
		SE	2.09	1.57	1.22
	ADHD	N	63	63	62
		Mean	84.97	72.49	79.11
		SD	16.43	13.03	10.04
		SE	2.07	1.642	1.275
	Total	N	125	126	123
		Mean	80.53	71.94	76.39
		SD	16.97	12.72	10.13
		SE	1.52	1.13	.91

Instruction x Group
$F(1,121) = 4.34$, $MSE = 475.83$, $p = .039$, $\eta_p^2 = .035$

Table 8

Mean Probability Estimates for Congruency x Group (% accuracy)

	Group		Conflict	Non Conflict	Total
Congruency x Group	Control	N	64	61	61
		Mean	62.73	84.81	73.63
		SD	14.34	9.56	9.54
		SE	1.79	1.22	1.22
	ADHD	N	64	62	62
		Mean	69.03	88.41	79.11
		SD	15.42	10.44	10.04
		SE	1.93	1.33	1.28
	Total	N	128	123	123
		Mean	65.88	86.63	76.39
		SD	15.16	10.14	10.13
		SE	1.34	.91	.91

Congruency x Group
$F(1,121) = 1.70$, $MSE = 255.20$, $p = .195$, $\eta_p^2 = .014$

Table 9

Mean Probability Estimates for Congruency x Instruction (% accuracy)

		Statistics	Beliefs	Totals
	N	128	128	128
	Conflict	71.81	59.96	65.88
	SD	27.57	24.54	15.163
	SE	2.44	2.17	1.34
	N	125	126	123
Congruency x Instruction	Non-Conflict	88.94	83.93	86.63
	SD	11.61	13.37	10.135
	SE	1.04	1.19	.914
	N	125	126	123
	Mean Totals	80.53	71.94	76.39
	SD	16.974	12.719	10.13
	SE	1.518	1.133	.91

Congruency x Instruction
$F(1,121) = 2.97$, $MSE = 536.04$, $p = .087$, $\eta_p^2 = .024$

Table 10

Mean Response Times (RTs) for Congruency x Instruction x Group (ms)

Group		Statistic	Belief	Totals
Control	N	60	64	60
	Conflict	15825.77	19455.88	17217.15
	SD	6714.81	10358.19	7246.88
	SE	866.88	1294.77	935.57
	N	62	63	62
	Non-Conflict	15331.02	16016.84	15612.94
	SD	7162.60	7488.01	6634.81
	SE	909.65	943.40	842.62
	N	59	63	59
	Mean Totals	15327.78	17514.64	16117.54
	SD	6224.30	7921.32	6405.56
	SE	810.34	997.99	833.933
ADHD	N	61	64	61
	Conflict	18399.95	22014.06	19771.38
	SD	6211.87	9907.34	6491.92
	SE	795.35	1238.42	831.20
	N	60	62	58
	Non-Conflict	15360.94	20400.91	17392.92
	SD	5174.63	9116.25	6035.90
	SE	662.69	1157.76	792.55
	N	58	62	57
	Mean Totals	16512.69	20962.09	18278.52
	SD	4749.60	8884.72	5838.49
	SE	623.65	1128.36	773.33

Group x Congruency x Instruction
$F(1,114) = 7.20$, $MSE = 15747438.89$, $p = .008$, $\eta_p^2 = .059$

Table 11

Mean Response Times (RTs) for Instruction x Group (ms)

		Statistics	Beliefs	Totals
Instruction x Group	N	59	63	59
	Control	15327.78	17514.64	16117.54
	SD	6224.30	7921.32	6405.56
	SE	810.24	997.99	833.93
	N	58	62	57
	ADHD	16512.69	20962.09	18278.52
	SD	4749.60	8884.72	5838.49
	SE	623.65	1128.36	773.33
	N	117	125	116
	Mean Totals	15915.17	19224.58	17179.40
	SD	5550.66	8555.77	6202.47
	SE	513.16	765.25	575.89

Instruction x Group
$F(1,114) = 2.51$, $MSE = 45600276.08$, $p = .116$, $\eta_p^2 = .022$

Table 12

Mean Response Times (RTs) for Congruency x Group (ms)

Group			Conflict	Non-Conflict	Total
Congruency x Group	Control	N	60	62	59
		Mean	17217.15	15612.94	16117.54
		SD	7246.88	6634.81	6405.56
		SE	935.57	842.62	833.93
	ADHD	N	61	58	57
		Mean	19771.38	17392.92	18278.52
		SD	6491.92	6035.90	5838.49
		SE	831.20	792.55	773.33
	Total	N	121	120	116
		Mean	18504.82	16473.26	17179.40
		SD	6966.92	6388.57	6202.48
		SE	633.36	583.19	575.89

Congruency x Group
$F(1,114) = .030$, $MSE = 21033843.88$, $p = .863$, $\eta_p^2 < .001$

Table 13

Mean Response Times (RTs) for Congruency x Instruction (ms)

			Statistics	Beliefs	Totals
Congruency x Instruction	Conflict	N	121	128	121
		Mean	17123.49	20734.97	18504.82
		SD	6567.41	10176.31	6966.92
		SE	597.05	899.50	633.36
	Non-Conflict	N	122	125	120
		Mean	15345.74	18191.34	16473.26
		SD	6238.59	8588.44	6388.57
		SE	564.82	768.17	583.19
	Total	N	117	125	116
		Mean	15915.95	19224.58	17179.40
		SD	5550.66	8555.70	6202.47
		SE	513.16	765.25	575.89

Congruency x Instruction
$F(1,114) = .104$, $MSE = 15747438.89$, $p = .748$, $\eta_p^2 = .001$

Table 14

Mean Confidence Ratings Congruency x Instruction x Group (1 – low; 9 – high)

Group		Statistic	Belief	Totals
Control	N	63	64	63
	Conflict	7.41	7.23	7.31
	SD	1.26	1.03	.95
	SE	.16	.13	.12
	N	64	64	64
	Non-Conflict	7.78	7.64	7.71
	SD	.98	.928	.82
	SE	.12	.12	.10
	N	63	64	63
	Mean Totals	7.59	7.43	7.51
	SD	1.03	.89	.82
	SE	.13	.11	.10
ADHD	N	63	63	62
	Conflict	7.31	6.90	7.09
	SD	1.32	1.07	1.03
	SE	.17	.14	.13
	N	64	63	63
	Non-Conflict	7.69	7.40	7.53
	SD	1.14	1.06	.96
	SE	.14	.13	.12
	N	63	63	62
	Mean Totals	7.51	7.15	7.31
	SD	1.16	1.00	.97
	SE	.15	.13	.12

Group x Congruency x Instruction
$F(1,123) = .089$, $MSE = .315$, $p = .765$, $\eta_p^2 = .001$

Table 15

Mean Confidence Ratings Instruction x Group (1 – low; 9 – high)

	Group		Statistics	Belief	Total
Instruction x Group	Control	N	63	64	63
		Mean	7.59	7.43	7.51
		SD	1.03	.89	.82
		SE	.13	.11	.10
	ADHD	N	63	63	62
		Mean	7.51	7.15	7.31
		SD	1.17	1.00	.97
		SE	.15	.13	.12
	Total	N	126	127	125
		Mean	7.55	7.29	7.41
		SD	1.10	.96	.90
		SE	.10	.09	.08

Instruction x Group
$F(1,123) = 1.15$, $MSE = .993$, $p = .286$, $\eta_p^2 = .009$

Table 16

Mean Confidence Ratings Congruency x Group (1 – low to 9 – high)

	Group		Conflict	Non-Conflict	Total
	Control	N	63	64	63
		Mean	7.31	7.71	7.51
		SD	.95	.82	.82
		SE	.12	.10	.10
Congruency x Group	ADHD	N	62	63	62
		Mean	7.09	7.53	7.31
		SD	1.03	.96	.97
		SE	.13	.12	.12
	Total	N	125	127	125
		Mean	7.20	7.62	7.41
		SD	1.00	.89	.90
		SE	.09	.08	.08

Congruency x Group
$F(1,123) = .288$, $MSE = .356$, $p = .592$, $\eta_p^2 = .002$

Table 17

Mean Confidence Ratings Congruency x Instruction (1 – low; 9 – high)

		Statistics	Beliefs	Totals
Congruency x Instruction	N	126	127	125
	Conflict	7.36	7.07	7.20
	SD	1.29	1.06	1.00
	SE	.11	.09	.09
	N	128	127	127
	Non-Conflict	7.73	7.52	7.62
	SD	1.06	1.00	.90
	SE	.09	.09	.08
	N	126	127	125
	Mean Totals	7.55	7.29	7.41
	SD	1.10	.96	.90
	SE	.98	.85	.08

Congruency x Instruction
$F(1,123) = .683$, $MSE = .315$, $p = .410$, $\eta_p^2 = .006$

Table 18

Mean CRT Percent Correct for Groups

	Group	N	Mean	Standard Deviation	Standard Error
CRT Percent Correct	Control	64	34.86	36.87	4.61
	ADHD	64	46.34	34.53	4.32

Equal Variances Assumed	Mean Difference	Standard Error of Mean	*df*	*t* value	Significance
p = .919	-11.48	6.31	126	1.82	*p* =. 071

Table 19

Mean CRT Response Times for Groups (ms)

	Group	N	Mean	Standard Deviation	Standard Error
CRT RT	Control	59	36626.88	22016.73	2818.95
	ADHD	61	46210.33	24920.33	3190.72

Mean difference in CRT Response Times between Groups (ms)

Equal Variances Assumed		Standard Error of Mean	*df*	*t* value	Significance
p = .016	-9583.45	4257.60	120	2.25	*p* =. 026

Table 20

CRT Pearson Correlations

		Group	CRT RT	CRT Percent Correct	Statistical Estimates	Belief Estimates
Group	Pearson Correlation	1	.201*	.160	.265**	.043
	Sig. (2-tailed)		.026	.071	.003	.631
	N	128	122	128	125	126
CRT RT	Pearson Correlation	.201*	1	-.063	-.114	.034
	Sig. (2-tailed)	.026		.489	.219	.716
	N	122	122	122	119	120
CRT Percent Correct	Pearson Correlation	.160	-.063	1	.374**	.023
	Sig. (2-tailed)	.071	.489		.000	.797
	N	128	122	128	125	126
Statistical Estimates	Pearson Correlation	.265**	-.114	.374**	1	-.090
	Sig. (2-tailed)	.003	.219	.000		.321
	N	125	119	125	125	123
Belief Estimates	Pearson Correlation	.043	.034	.023	-.090	1
	Sig. (2-tailed)	.631	.716	.797	.321	
	N	126	120	126	123	126

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 21

CRT Pearson Correlations by Group

Correlations Group			CRT RT	CRT Percent Correct	Statistical Estimates	Belief Estimates	Statistical RT	Belief RT
Control	CRT RT	Pearson Correlation	1	-.245	-.153	.027	.386**	.251
		Sig. (2-tailed)		.057	.247	.839	.003	.053
		N	61	61	59	60	56	60
	CRT Percent Correct	Pearson Correlation	-.245	1	.374**	-.006	-.071	.129
		Sig. (2-tailed)	.057		.003	.962	.593	.315
		N	61	64	62	63	59	63
	Statistical Estimates	Pearson Correlation	-.153	.374**	1	-.170	-.050	.249
		Sig. (2-tailed)	.247	.003		.191	.709	.053
		N	59	62	62	61	57	61
	Belief Estimates	Pearson Correlation	.027	-.006	-.170	1	.011	-.103
		Sig. (2-tailed)	.839	.962	.191		.933	.426
		N	60	63	61	63	58	62
	Statistical RT	Pearson Correlation	.386**	-.071	-.050	.011	1	.670**
		Sig. (2-tailed)	.003	.593	.709	.933		.000
		N	56	59	57	58	59	59
	Belief RT	Pearson Correlation	.251	.129	.249	-.103	.670**	1
		Sig. (2-tailed)	.053	.315	.053	.426	.000	
		N	60	63	61	62	59	63
ADHD	CRT RT	Pearson Correlation	1	.034	-.182	.033	.066	-.048
		Sig. (2-tailed)		.795	.163	.804	.629	.715
		N	61	61	60	60	56	59
	CRT Percent Correct	Pearson Correlation	.034	1	.331**	.039	-.201	.018
		Sig. (2-tailed)	.795		.008	.759	.130	.887
		N	61	64	63	63	58	62
	Statistical Estimates	Pearson Correlation	-.182	.331**	1	-.052	-.221	.160
		Sig. (2-tailed)	.163	.008		.691	.099	.219
		N	60	63	63	62	57	61
	Belief Estimates	Pearson Correlation	.033	.039	-.052	1	-.026	-.210
		Sig. (2-tailed)	.804	.759	.691		.847	.104
		N	60	63	62	63	57	61
	Statistical Instruction RT	Pearson Correlation	.066	-.201	-.221	-.026	1	.481**
		Sig. (2-tailed)	.629	.130	.099	.847		.000
		N	56	58	57	57	58	57
	Belief Instruction RT	Pearson Correlation	-.048	.018	.160	-.210	.481**	1
		Sig. (2-tailed)	.715	.887	.219	.104	.000	
		N	59	62	61	61	57	62

**. Correlation is significant at the 0.01 level (2-tailed).

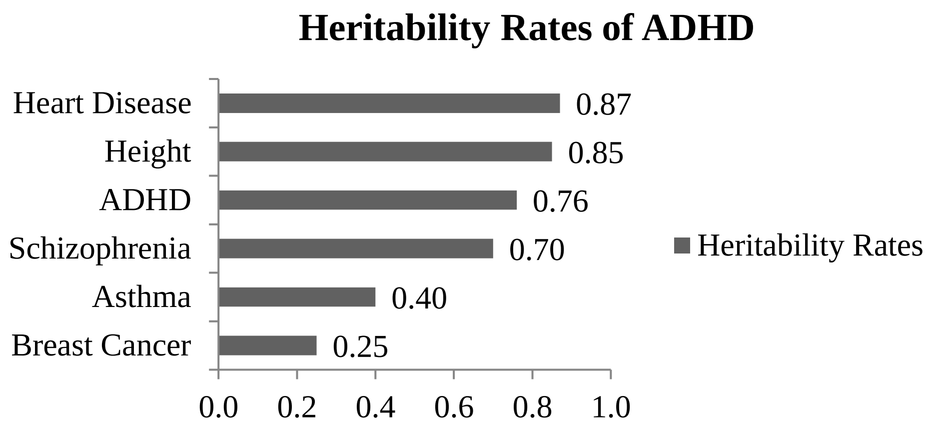

Figure 1. Heritability rates of ADHD (Faraone & Biederman, 1998)

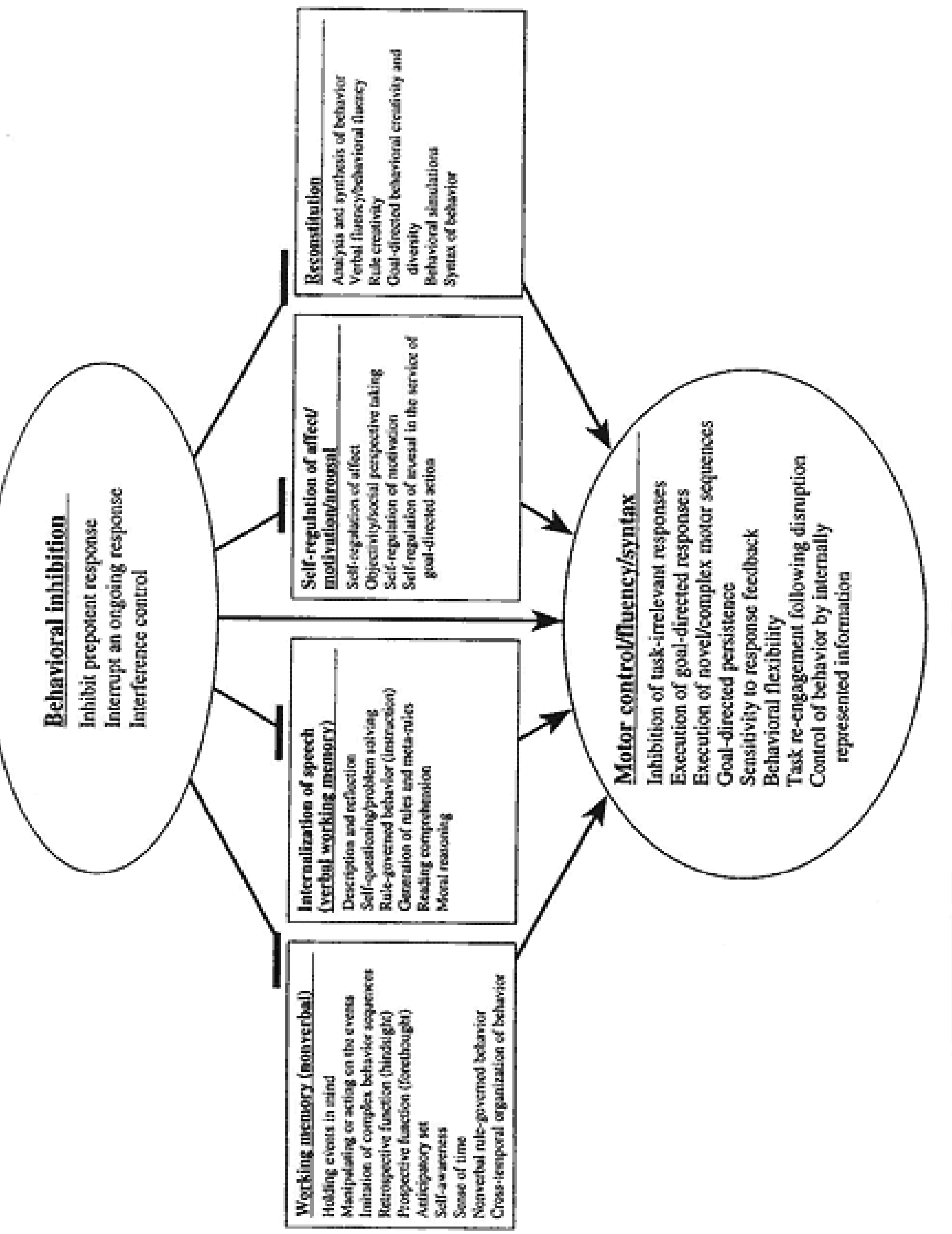

Figure 2. Diagram illustrating the complete hybrid model of executive functions (boxes) and the relationship of these four functions to the behavioural inhibition and motor control systems. From Barkley (1997a).

Probability Estimates for Congruency x Group x Response

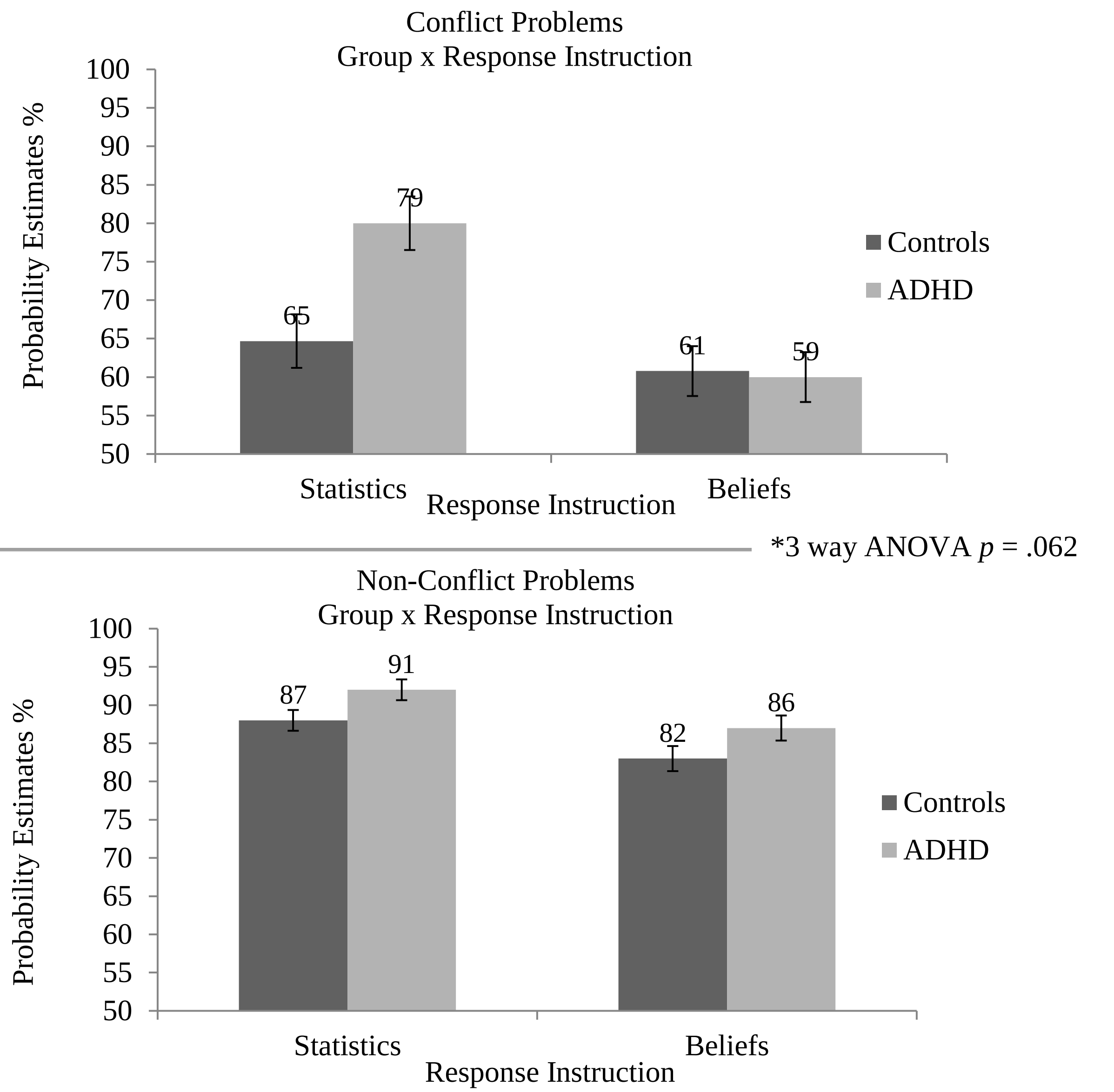

Figure 3. Mean probability estimates (%) for Congruency x Group x Response Instruction revealing a marginally significant 3-way interaction (p = .062), such that the ADHD group had significantly higher estimates relative to controls when resolving conflict problems with statistics. Symmetrical response patterns for the control group on conflict problems illustrate 2-way interference, such that interference from beliefs influences estimates when solving with statistics and interference from statistics influences estimates when solving with beliefs. Standard errors are represented in the figure by the error bars attached to each column.

Probability Estimates for Group x Response Instruction

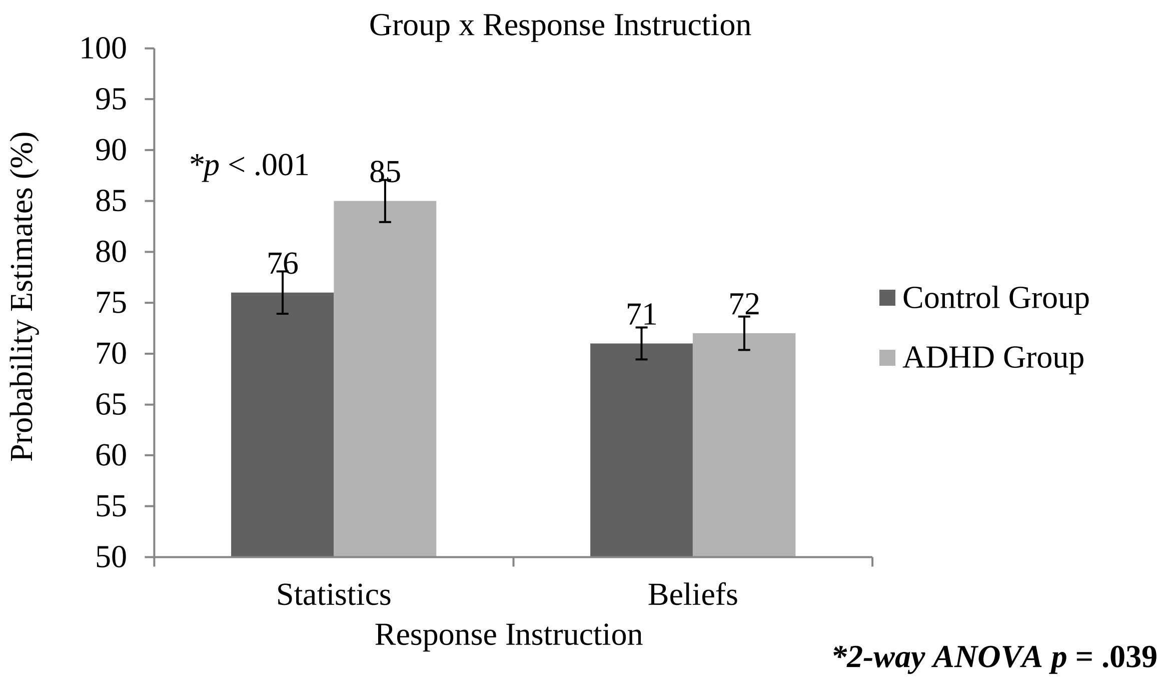

Figure 4. Mean probability estimates (%) for Group x Response Instruction conditions. The graph demonstrates an interaction ($p = .039$), such that the effect of the response instruction was reliably greater for the ADHD group relative to the control group. Significantly higher accuracies of estimates were observed for the ADHD group when responding according to statistics, but not when responding with beliefs, whereas estimates for the control group were similar for both instruction conditions. Standard errors are represented in the figure by the error bars attached to each column.

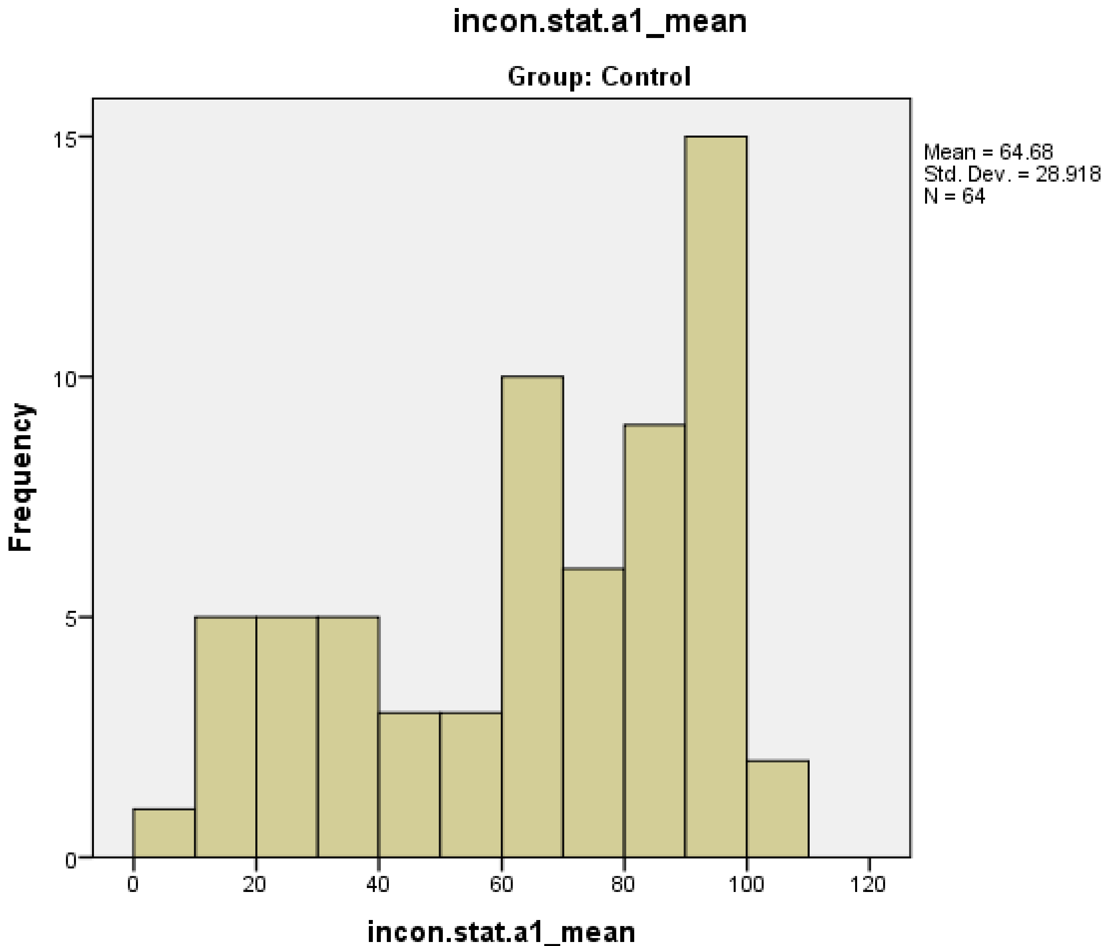

Figure 5. Histogram of probability estimates for control group participants when solving conflict problems under the statistics instruction. The histogram shows the distribution to be approximately symmetric with skewness of –0.491 (SE = .299) and kurtosis of –0.983 (SE = .590), considered somewhat platykurtic.

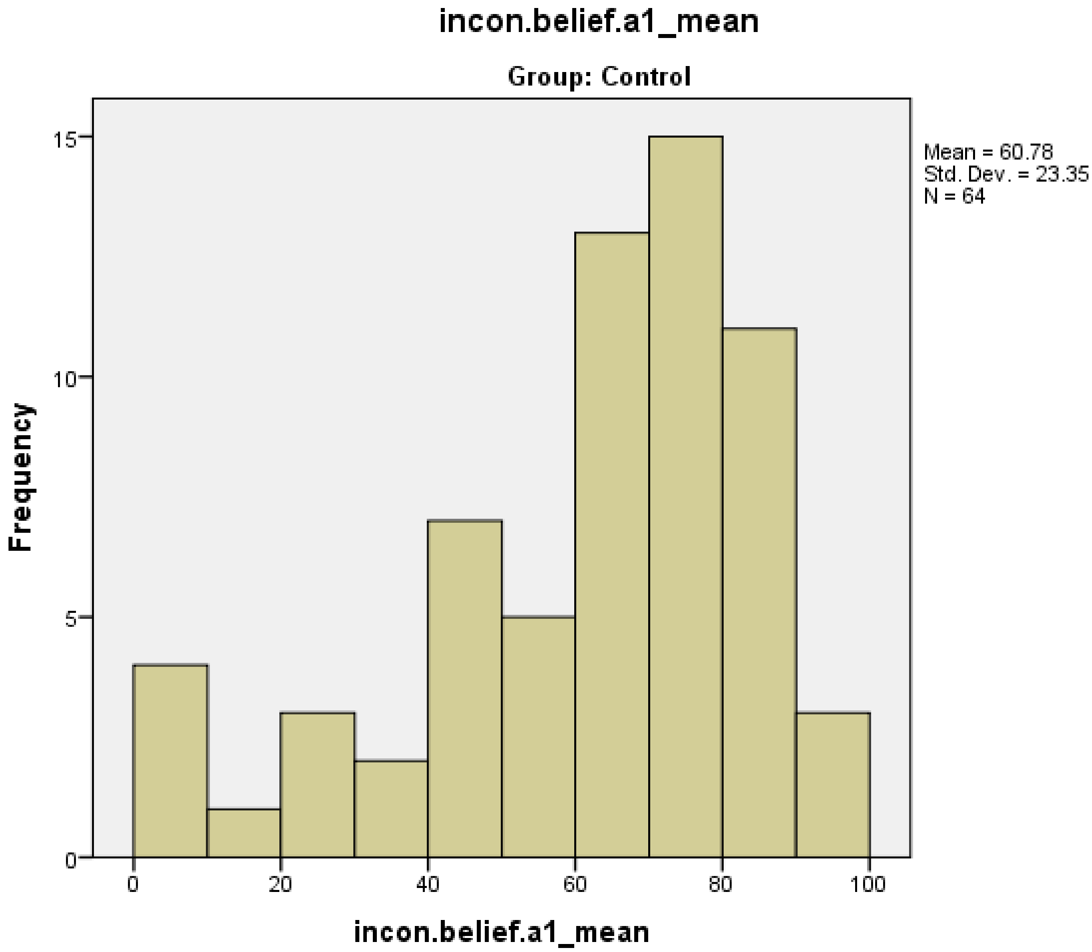

Figure 6. Histogram of probability estimates for control group participants when solving conflict problems under the belief instruction. The histogram shows the distribution to be moderately skewed to the left, with skewness of –0.992 (SE = .299) and kurtosis of .302 (SE = .590).

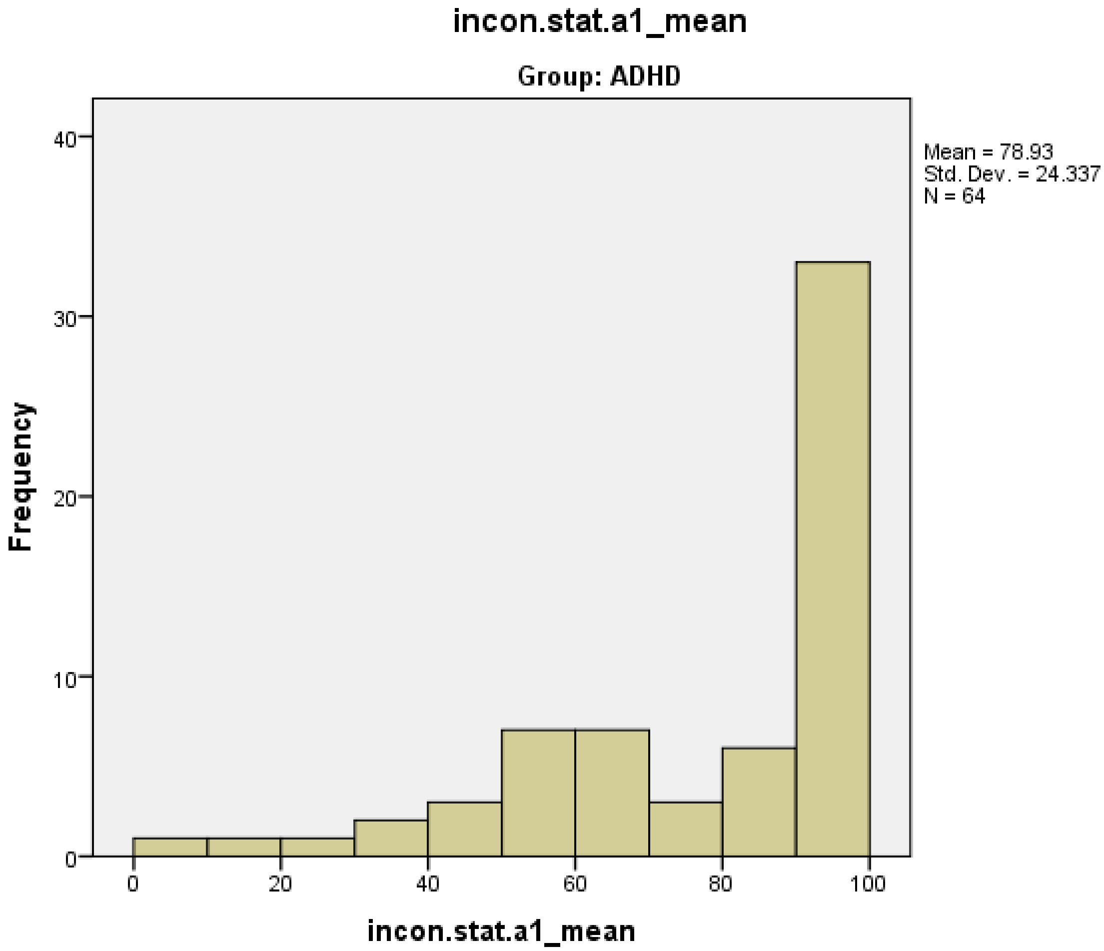

Figure 7. Histogram of probability estimates for ADHD group participants when solving conflict problems under the statistics instruction. The histogram shows the distribution to be highly skewed to the left, with skewness of – 1.084 (SE = .299) and kurtosis of .298 (SE= .590).

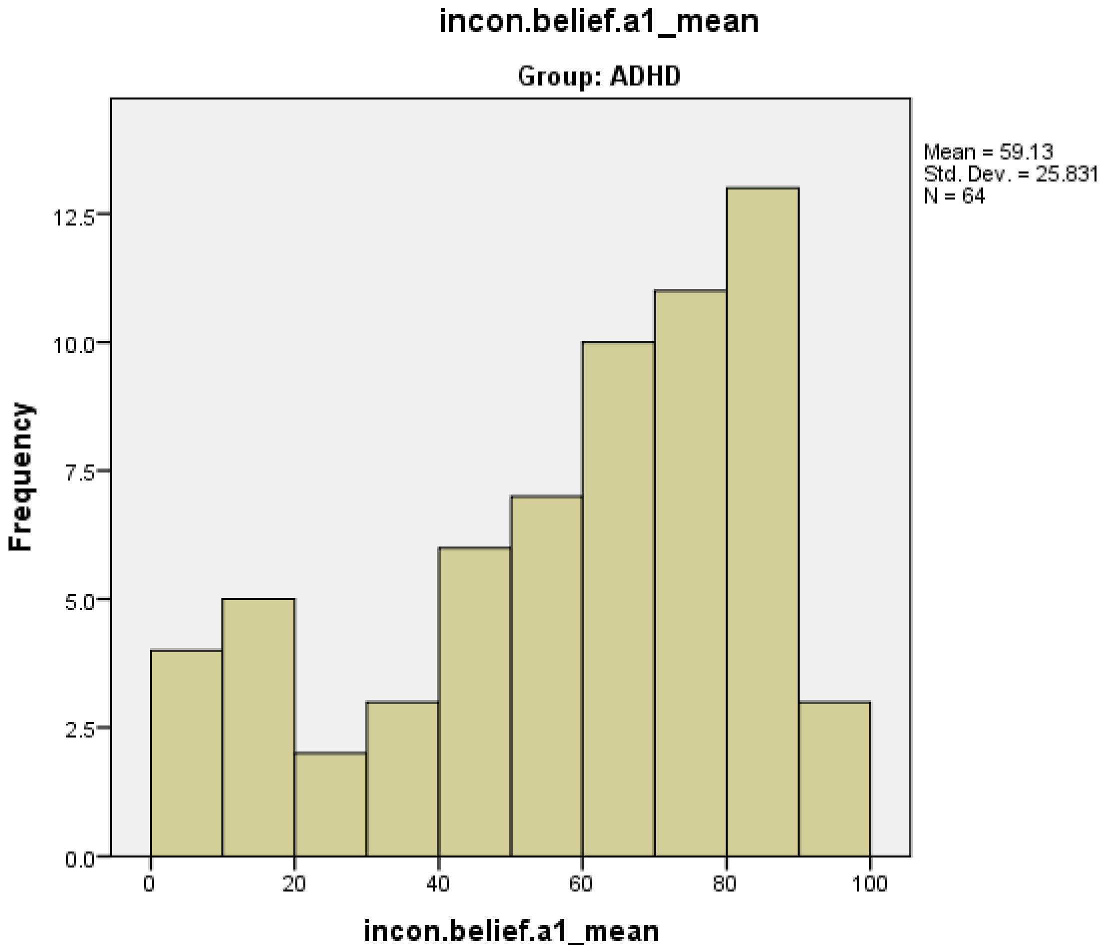

Figure 8. Histogram of probability estimates for ADHD group participants when solving conflict problems under the belief instruction. The histogram shows the distribution to be moderately skewed to the left, with skewness of –0.721 (SE = .299) and kurtosis of –0.464 (SE = .590), considered somewhat platykurtic.

Response Times (ms) for Congruency x Group x Response Instruction

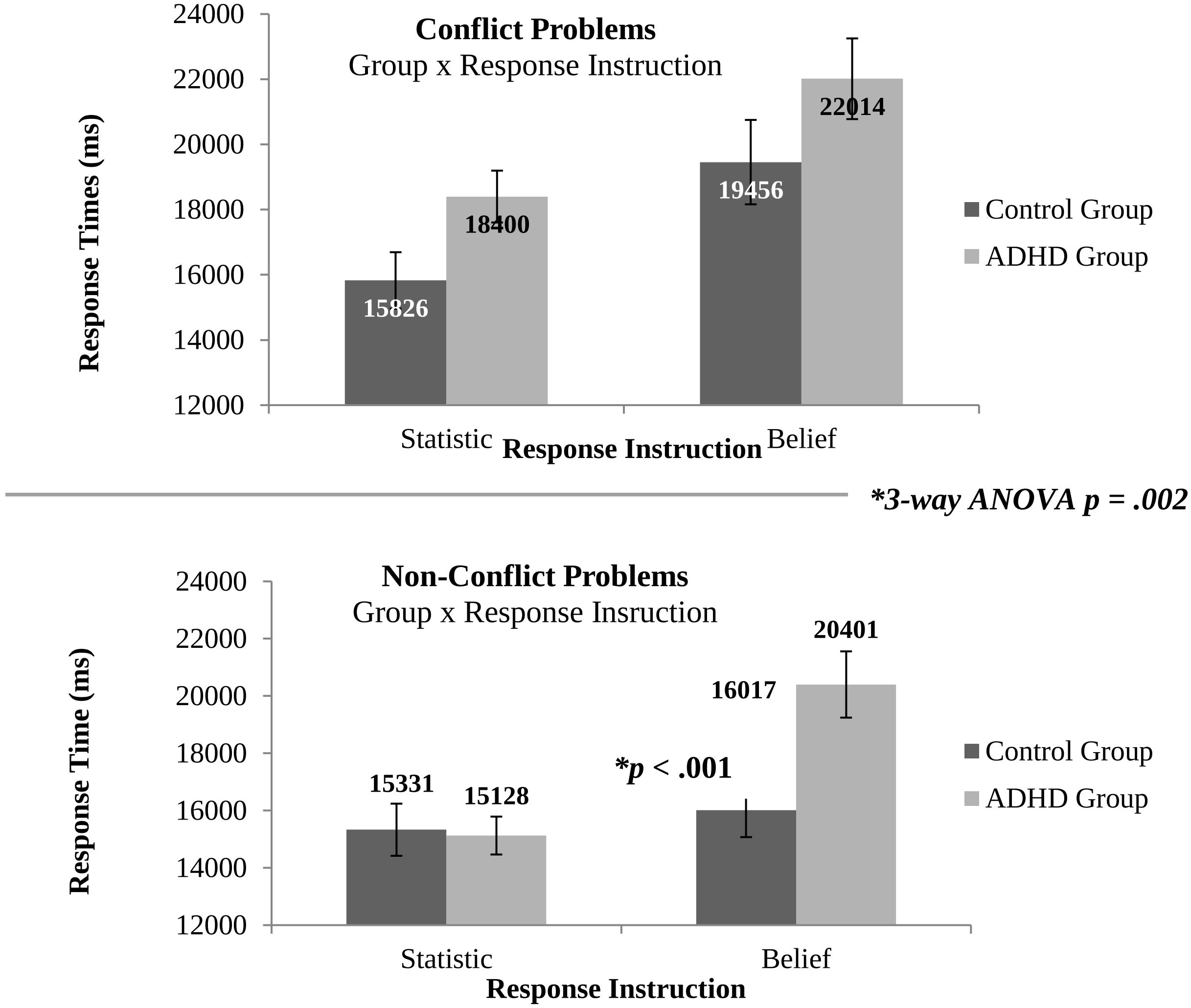

Figure 9. Mean RTs (ms) for Congruency x Group x Instruction revealing a 3-way interaction, such that the ADHD group had significantly longer response latencies relative to the control group when solving non-conflict problems with beliefs. Standard errors are represented in the figure by the error bars attached to each column.

Response Times (ms) for Congruency x Group x Response Instruction

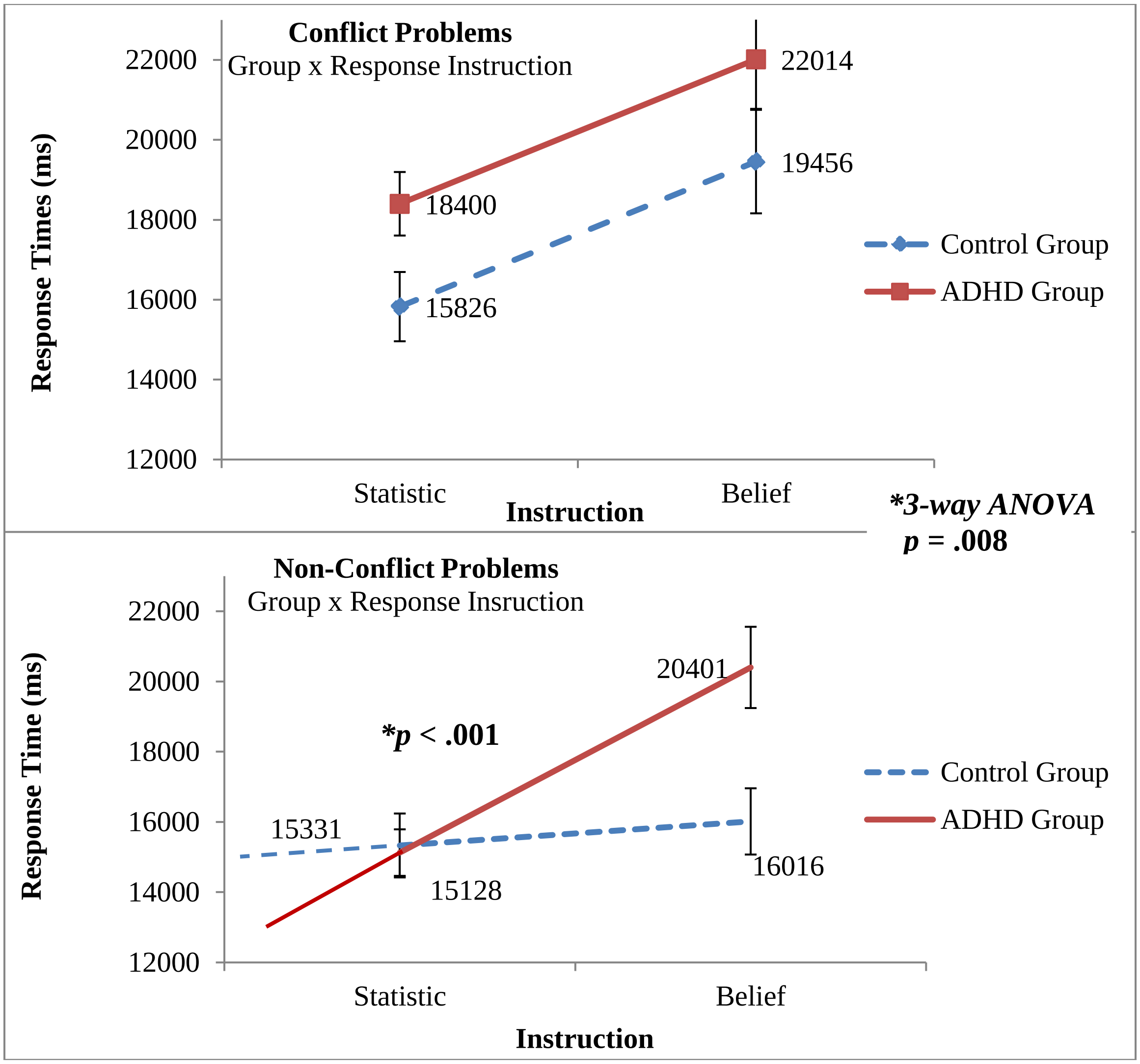

Figure 10. Deconstruction of the 3-way interaction (F(114) = 7.20, p = .008) for RTs for variables of Congruency x Group x Instruction. A two-way ANOVA revealed conflict problems to have main effects of both group (F(1,119) = 4.17, p = .043) and instruction (F(1,119) = 12.77, p = .001), but no interaction effects F(119) = .001, p = .979. A second two-way ANOVA for non-conflict problems revealed no main effect of group (F(118) = 2.35, p = 1.28), but a main effect of instruction (F(1,118) = 15.37, p < .001), qualified by a two-way interaction between group and response instruction (F(1,118) = 9.32, p = .003). Paired - tests revealed that the control group's RT for non-conflict problems were similar for both belief and statistic instructions (t(61) = .715, p = .478). However, the ADHD group had significantly longer RTs when resolving non-conflict problems with beliefs relative to statistics (t(57) = 4.33, p <.001).

Appendix A

Study Invitation

Posted as a general announcement on PAWS

Participants needed for a 30 minute study on "Differences in Reasoning Performance."

Using the laboratory's computer, participants will be asked to read, evaluate, and provide judgment decisions on 27 reasoning problems. All responses will be confidential and no information will be linked to your identity or shared with others.

A participation fee of $10.00 will be paid to complete the 30 minute reasoning task.

Participants will be asked to pick one of the scheduled times provided for testing at the Social Science Research Laboratory, Room 256, 2nd Floor of the Arts and Science building at the University of Saskatchewan.

To arrange an appointment to participate in this study, please email the researcher at maia.gibb@usask.ca

If you have already participated in this study, you are not eligible to participate again.

The study has been approved by the University of Saskatchewan Research Ethics Board.

For more information, contact:

Graduate Studies Researcher: Maia Gibb, email: maia.gibb@usask.ca
Research Supervisor: Dr. Laurie Hellsten, email: laurie.hellsen@usask.ca

Appendix B

U of S Study Invitation

This announcement was posted as a general bulletin on PAWS to recruit participants diagnosed with ADHD and also emailed to students registered at the university's Disability Services for Students (DSS) as having ADHD. Emails were sent directly by the DSS office on behalf of the researcher. To protect students' privacy, the researcher did not have access to the DSS database or email list.

Have you been diagnosed with ADHD? Do you have 30 minutes to participate in a study?

We are seeking participants diagnosed with ADHD to partake in a study that explores "Reasoning Performance."

Using the laboratory's computer, participants will be asked to read, evaluate, and provide judgment decisions on 27 reasoning problems. All responses will be confidential and no information will be linked to your identity or shared with others.

A participation fee of $10.00 will be paid to complete the 30 minute reasoning task.

Participants will be asked to pick one of the scheduled times provided for testing at the Social Science Research Laboratory, Room 256, 2nd Floor of the Arts and Science building at the University of Saskatchewan.

To arrange an appointment to participate in this study, please email the researcher at mkg639@mail.usask.ca

If you are taking medication to control symptoms of ADHD, an appointment should be made 12 - 24 hours after your last dose of medication, depending on how often the medication is taken. Flexible appointment times are available so as not to disrupt medication schedules. For example, if you normally take medication for ADHD ONCE DAILY at 9 a.m., an appointment would ideally be scheduled at 9:00 p.m. the following day before the next dose of medication is due. Alternatively, if medication for ADHD is taken TWICE DAILY, an appointment would ideally be scheduled at least 12 hours after a taking ADHD medication but before the next dose is due to be taken.

If you have already participated in this study, you are not eligible to participate again.
The study has been approved by the University of Saskatchewan Research Ethics Board (BEH 15-147)
For more information, contact:

Graduate Studies Researcher: Maia Gibb, email: maia.gibb@usask.ca.
Research Supervisor: Dr. Laurie Hellsten, email: laurie.hellsen@usask.ca.

Appendix C

Consent Form

Project Title:
Differences in Reasoning Performance

Researchers:
Maia Gibb, Graduate Student, Educational Psychology and Special Education, University of Saskatchewan, maia.gibb@usask.ca

Supervisor:
Dr. Laurie Hellsten, Educational Psychology and Special Education, University of Saskatchewan, (306) 966-7723, laurie.hellsen@usask.ca

Purpose(s) and Objective(s) of the Research:
The primary purpose of this study is to train the student-researcher in the methods of psycho-educational research. As well, we wish to examine differences in reasoning performance between individuals diagnosed with Attention Deficit/Hyperactivity Disorder (ADHD) and those not having ADHD.

Procedure:
Using a computer, you will be asked to read and make judgment evaluations on two reasoning tasks. In the first task, you are asked to evaluate 24 belief-logic problems, each of which describe a sample of people and provide a personality sketch of an individual drawn at random from the sample. The second task asks you to answer three logic questions. At the end of the study, you will be provided a debriefing form. This study should take approximately **30** minutes of your time. Please feel free to ask any questions regarding the procedures and goals of the study or your role, by e-mailing the researchers at the addresses listed above.

Potential Risks:
There are no known or anticipated physical, psychological, or social risks to you by participating in this research. At the completion of the study, you will be given a sheet that explains the study in more detail and you will be provided the opportunity to ask questions.

Compensation:
You will receive a cash payment of $10.00 for your participation in the study. If you choose to withdraw at any time during the study task, compensation for your services will be prorated based on the number of minutes of participation.

Confidentiality:
Your data will be kept completely confidential and no personally identifying information will be linked to your data. Data will be coded using arbitrary participant numbers and will not be associated with any names or personally identifying information. All data will be summarized in a combined form.

Storage of Data:
Data and consent forms will be stored separately in a secure location at the University of Saskatchewan by the researcher and research supervisor. In instances where the data are published in an academic journal and/or presented at a professional conference, the data will be stored for a minimum of five years after completion of the study. When the data are no longer required, they will be destroyed beyond recovery.

Right to Withdraw:
Your participation is voluntary and you may answer only those questions that you are comfortable with. You may withdraw from the research project for any reason, at any time during the study task, without explanation or penalty. You have the right to withdraw from the study at any time during the tasks, up until you have left the laboratory. Once you have completed the study and left, it is no longer possible to identify individual responses from the assigned numerical identity.

If you withdraw at any time during the study task, partial compensation for your services will be provided at a prorated amount based on the number of minutes of participation. If you choose to withdraw from study, you will be provided a debriefing form with information about the study and contact information, should you wish to contact the researchers. Any data that you have contributed up until your decision to withdraw will be destroyed beyond recovery.

Follow up:
To obtain results from the study, please use the contact information given to you on the debriefing form. The student-researcher would be more than happy to provide summarized results of the study to participants.

Questions or Concerns:
For any questions or concerns please contact the student-researchers using the information provided. You may also contact the student-researcher by email: maia.gibb@usask.ca or the research supervisor, Dr. Laurie Hellsten, Educational Psychology and Special Education, University of Saskatchewan, (306) 966-7723, laurie.hellsen@usask.ca. Questions about your rights as a participant may be addressed to the Research Ethics Office at ethics.office@usask.ca or phone (306) 966-2975. Out of town participants may call toll free (888) 966-2975.

Signed Consent
Your signature below indicates that you have read and understand the description provided: I have had an opportunity to ask questions and my/our questions have been answered. I consent to participate in the research project. A copy of this Consent Form has been given to me for my records.

________________________ ________________________ ____________

Name of Participant *Signature* *Date*

________________________ ________________________

Researcher Signature *Date*

Appendix D

Debriefing Form

The primary purpose of this study is to train the student-researcher in the methods of psycho-educational research. The secondary purpose of this study is to examine differences in reasoning performance between individuals diagnosed with Attention Deficit/Hyperactivity Disorder (ADHD) and those not having ADHD. It is hypothesized that individuals diagnosed with ADHD will have more difficulty when solving belief-based probability problems using statistics in comparison to those without ADHD. This hypothesis is derived from research demonstrating that a key functional area of the brain implicated in ADHD is the same cortical area normally activated when an erroneous response requires suppression in analytic (logical) reasoning.

To test this, we designed an experiment asking participants to give an estimate on the probability or likelihood of group membership. Participants evaluated 24 problems, each of which provided information about the composition of a particular sample (e.g., 4 doctors and 996 nurses) and a stereotypical description of one individual drawn from that sample. These problems varied in the proportion of individuals that belonged to one of the two groups. In some cases the description of the individual in the problem matched the presented base-rates of group membership (non-conflict problems). In other cases, the description conflicted with the presented base-rates of group membership (conflict problems). Participants were instructed to solve the problems using either "statistics" or "beliefs." Responses were given in free time in the form of a probability estimate. Based on previous research, we anticipate that when individuals with ADHD are asked to solve conflict problems by way of "statistics," they will have more difficulty than the control group in inhibiting the erroneous "belief" response cued by the stereotypical description.

The data will be used as the basis for a master's thesis in educational psychology to better understand how individuals with ADHD perform in logical/probability reasoning on applied problems as compared to individuals without ADHD. Your data will be kept completely confidential and no personally identifying information will be linked to your data. Normally, the data will be destroyed once the thesis has been completed. In instances where the data are published in an academic journal and/or presented at a professional conference, the data will be stored for a minimum of five years after completion of the study**.** When the data are no longer required, it will be destroyed beyond recovery.

If you have any concerns or questions about this research, please feel free to contact the student-researcher: Maia Gibb, email: mkg639@mail.usask.ca. Alternatively, you may also contact the supervisor, Dr. Laurie Hellsten, email: laurie.hellsen@usask.ca, or phone (306) 966-7723.

You are also encouraged to contact the researchers for a copy of the results which should be available by October, 2016. Any questions regarding your rights as a participant may be addressed to the Behavioural Research Ethics board through the Research Ethics Office at ethics.office@usask.ca, or by calling (306) 966-2975. Out of town participants call toll free (888) 966-2975. Thank you again for helping us with this research.

Appendix E

Experimental Stimuli Study Task 1

In a study 1000 people were tested. Jack is a randomly chosen participant of this study.	Among the participants there were 5 engineers and 995 lawyers.	Jack is 36 years old. He is not married and is somewhat introverted. He likes to spend his free time reading science fiction and writing computer programs.	What is the probability that Jack is a lawyer?
In a study 1000 people were tested. Kurt is a randomly chosen participant of this study.	Among the participants there were 3 who live in a condo and 997 who live in a farmhouse.	Kurt works on Wall Street and is single. He works long hours and wears Armani suits to work. He likes wearing sunglasses.	What is the probability that Kurt lives in a farmhouse?
In a study 1000 people were tested. Paul is a randomly chosen participant of this study.	Among the participants there were 997 nurses and 3 doctors.	Paul is 34 years old. He lives in a beautiful home in a posh suburb. He is well spoken and very interested in politics. He invests a lot of time in his career.	What is the probability that Paul is a doctor?
In a study 1000 people were tested. Jessie is a randomly chosen participant of the study.	Among the participants there were 996 women and 4 men.	Jessie is 23 years old and is finishing a degree in engineering. On Friday nights, Jessie likes to go out with friends and listen to loud music and drink beer.	What is the probability that Jessie is a man?
In a study 1000 people were tested. Jeremy is a randomly chosen participant of this study.	Among the participants there were 4 whose favorite series is Star Trek and 996 whose favorite series is Days of our Lives.	Jeremy is 26 and is doing graduate studies in physics. He stays at home most of the time and likes to play video-games.	What is the probability that Jeremy's favorite series is Days of Our Lives?
In a study 1000 people were tested. Ellen is a randomly chosen participant of this study.	Among the participants there were 995 fifty-year olds and 5 sixteen-year olds.	Ellen likes to listen to hip hop and rap music. She enjoys wearing tight shirts and jeans. She's fond of dancing and has a small nose piercing.	What is the probability that Ellen is sixteen?
In a study 1000 people were tested. Karen is a randomly chosen participant of this study.	Among the participants there were 5 who buy their clothes at Wal-Mart and 995 who buy their clothes at high-end retailers.	Karen is a 33-year-old female. She works in a business office and drives a Porsche. She lives in a fancy penthouse with her boyfriend.	What is the probability that Karen buys her clothes at Wal-Mart?

In a study 1000 people were tested. Kelly is a randomly chosen participant of this study.	Among the participants there were 3 boys and 997 girls.	Kelly is 13 years old. Kelly's favorite subject is art. Kelly's favorite things to do are shopping and having sleepovers with friends to gossip about other kids at school.	What is the probability that Kelly is a boy?
In a study 1000 people were tested. Jay is a randomly chosen participant of this study.	Among the participants there were 997 who have a tattoo and 3 without a tattoo.	Jay is a 29-year-old male. He has served a short time in prison. He has been living on his own for 2 years now. He has an older car and listens to punk music.	What is the probability that Jay has a tattoo?
In a study 1000 people were tested. Lilly is a randomly chosen participant of this study.	Among the participants there were 996 kindergarten teachers and 4 executive managers.	Lilly is 37 years old. She is married and has 3 kids. Her husband is a veterinarian. She is committed to her family and always watches the daily cartoon shows with her kids.	What is the probability that Lilly is a kindergarten teacher?
In a study 1000 people were tested. Tara is a randomly chosen participant of this study.	Among the participants there were 4 Bruce Springsteen fans and 996 Britney Spears fans.	Tara is 15. She loves to go shopping at the mall and to talk with her friends about their crushes at school.	What is the probability that Tara is a Bruce Springsteen fan?
In a study 1000 people were tested. Martine is a randomly chosen participant of this study	Among the participants there were 995 French people and 5 Americans.	Martine is 26 years old. She is bilingual and reads a lot in her spare time. She is a very fashionable dresser and a great cook.	What is the probability that Martine is French?
In a study 1000 people were tested. Brannon is a randomly chosen participant of this study.	Brannon is 29 years old. He is very good with numbers but is shy around people. He spends much of his time working.	Among the participants there were 5 accountants and 995 street artists.	What is the probability that Brannon is an accountant?
In a study 1000 people were tested. Floyd is a randomly chosen participant of this study.	Floyd 40 years old. He is an imaginative person and enjoys street theatre. He loves experimenting with different types of food.	Among the participants there were 3 artists and 997 consultants.	What is the probability that Floyd is an artist?

In a study 1000 people were tested. Geraldine is a randomly chosen participant of this study.	Geraldine is 41 years old. She loves books and spends a lot of her free time reading. She enjoys helping her two children with their homework.	Among the participants there were 997 drummers and 3 librarians.	What is the probability that Geraldine is a drummer?
In a study 1000 people were tested. Tyrone is a randomly chosen participant of this study.	Tyrone is 27 years old. All his friends consider him very brave and he is in relatively good physical shape. He goes to the gym regularly.	Among the participants there were 996 managers and 4 firemen.	What is the probability that Tyrone is a manager?
In a study 1000 people were tested. Hank is a randomly chosen participant of this study.	Hank is 42 years old. He is a creative and introverted person. He considers his home computer his most prized possession.	Among the participants there were 4 writers and 996 construction workers.	What is the probability that Hank is a writer?
In a study 1000 people were tested. Molly is a randomly chosen participant of this study.	Molly is 25 years old. She is very healthy and she works out at least five times a week. She enjoys pop music and dancing.	Among the participants there were 995 researchers and 5 aerobics instructors.	What is the probability that Molly is a researcher?
In a study 1000 people were tested. Richard is a randomly chosen participant of this study.	Richard is 56 years old. He is a good public speaker and is good at meeting people. He is a top notch debater and can argue both sides of an issue with ease.	Among the participants there were 5 I.T. Technicians and 995 politicians.	What is the probability that Richard is a politician?
In a study 1000 people were tested. Lucius is a randomly chosen participant of this study.	Lucius is 34 years old. He is pretty aggressive and tends to get involved in bar fights more than the average person. He recently got divorced.	Among the participants there were 3 hippies and 997 boxers.	What is the probability that Lucius is a boxer?
In a study 1000 people were tested. Dianna is a randomly chosen	Dianna is 59 years old. She loves children and has been employed at her current job for 7 years. She enjoys drinking tea and	Among the participants there were 997 nannies and 3 telemarketers.	What is the probability that Dianna is a telemarketer?

participant of this study.	visiting with family and friends.		

In a study 1000 people were tested. George is a randomly chosen participant of this study.	George is 36 years old. He is very intelligent and has nerves of steel. He has great hand-eye coordination.	Among the participants there were 996 airplane pilots and 4 shop assistants.	What is the probability that George is a shop assistant?
In a study 1000 people were tested. Corinne is a randomly chosen participant of this study.	Corinne is 32 years old. She is a great organizer and always dresses neatly. She loves talking to her friends and family on the phone.	Among the participants there were 4 gardeners and 996 secretaries.	What is the probability that Corinne is a secretary?
In a study 1000 people were tested. Dan is a randomly chosen participant of this study.	Dan is 30 years old. He is a good driver and a takes his job very seriously. He is married, but has no children.	Among the participants there were 995 paramedics and 5 clowns.	What is the probability that Dan is a clown?

Appendix F

Counterbalancing Format

Conflict Problems (12 problems total) **(description matches smaller base-rate)**	**Non-Conflict problems (12 problems total)** **(description matches larger base-rate)**
Instructed to Respond with Statistics	**Instructed to Respond with Statistics**
Represented in Set One as: 5 Engineers vs. 995 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **third** sentence Instructions to respond using **statistics**	**Represented in Set Three as:** 995 Engineers vs. 5 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **third** sentence Instructions to respond using **statistics**
Represented in Set Two as: 5 Engineers vs. 995 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **fourth** sentence Instructions to respond using **statistics**	**Represented in Set Four as:** 995 Engineers vs. 5 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **fourth** sentence Instructions to respond using **statistics**
Represented in Set Five as: 5 Engineers vs. 995 Lawyers Question asks probability person is an **engineer** Base-rates presented in **third** sentence Instructions to respond using **statistics**	**Represented in Set Six as:** 955 Engineers vs. 5 Lawyers Question asks probability person is an **engineer** Base-rates presented in **third** sentence Instructions to respond using **statistics**
Represented in Set Seven as: 5 Engineers vs. 995 Lawyers Questions asks probability person is an **engineer** Base-rates presented in **fourth** sentence Instructions to respond using **statistics**	**Represented in Set Eight as:** 995 Engineers vs. 5 Lawyers Questions asks probability person is an **engineer** Base-rates presented in **fourth** sentence Instructions to respond using **statistics**

Conflict Problems **(description matches smaller base-rate)**	**Non-Conflict problems** **(description matches larger base-rate)**
Instructed to Respond with Beliefs	**Instructed to Respond with Beliefs**
Represented in Set Nine as: 5 Engineers vs. 995 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **third** sentence Instructions to respond using **belief**	**Represented in Set Eleven as:** 995 Engineers vs. 5 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **third** sentence Instructions to respond using **belief**
Represented in Set Ten as: 5 Engineers vs. 995 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **fourth** sentence Instructions to respond using **belief**	**Represented in Set Twelve as:** 995 Engineers vs. 5 Lawyers Question asks probability person is a **lawyer** Base-rates presented in **fourth** sentence Instructions to respond using **belief**

Represented in Set Thirteen as: 5 Engineers vs. 995 Lawyers Question asks probability person is an **engineer** Base-rates presented in **third** sentence Instructions to respond using **belief**	**Represented in Set Fourteen as:** 955 Engineers vs. 5 Lawyers Question asks probability person is an **engineer** Base-rates presented in **third** sentence Instructions to respond using **belief**
Represented in Set Fifteen as: 5 Engineers vs. 995 Lawyers Questions asks probability person is an **engineer** Base-rates presented in **fourth** sentence Instructions to respond using **belief**	**Represented in Set Sixteen as:** 995 Engineers vs. 5 Lawyers Questions asks probability person is an **engineer** Base-rates presented in **fourth** sentence Instructions to respond using **belief**

Appendix G

Experimental Stimuli Study Task 2

(1) A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?

(2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

(3) In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?